Marine air

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Marine air: shipping emissions in ports and their impact on local air quality

A case study on the ports of Delfzijl and Eemshaven

By:

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Loading salt in Delfzijl. Marten Klompien, 1961

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GRONINGEN SEAPORTS

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A case study on the ports of Delfzijl and Eemshaven

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Table of contents

Foreword and acknowledgements

This report is my master thesis of the Master Energy and Environmental Sciences at the University of Groningen performed in the second semester of the academic year 2011/2012. The research has been performed in an internship at Groningen Seaports, the port authority of two Dutch commercial shipping ports. The subject of this thesis was on the magnitude of ship air pollutant emissions in these ports and the resulting pollutant atmospheric concentration and deposition.

This study gave me as a former sailor the opportunity to gain more understanding of another maritime environmental problem. My former research topic dealt with ballast water and was more ecologically oriented (Van der Meer, 2012). The actual topic is related to the effects of energy (*i.e.* fuel) use. This study provided me more insight in a holistic view of shipping as a potential contributor to environmental degradation.

I would like to extend special thanks to my supervisors, Karin Ree MSc and Prof Ton Schoot Uiterkamp of the University of Groningen and my supervisor at Groningen Seaports, Geert-Jan Reinders for their critical view on my work and for their supportive comments; as well as for having letting me perform this study at Groningen Seaports. Thanks also to Volker Matthias PhD of the Helmholtz-Zentrum Geesthacht – Zentrum für Material- und Küstenforschung for introducing me to atmospheric modelling. And thanks to Rinkje Molenaar PhD of DCMR Milieudienst Rijnmond for supporting me with the atmospheric transport model OPS.

Delfzijl, 19 October 2012

Waddensea area in the Northern Netherlands (photograph by G.J. Reinders)

Abstract

Shipping is a significant air pollution source in ports and coastal areas. This study aims to quantify ship NO_X, SO_2, and PM emissions and their contribution to local atmospheric air pollution in the ports of Groningen Seaports. This study is performed to evaluate the relevance of shipping as an air polluter, and whether shore power is an effective emission reduction measure. The annual emissions and resulting concentrations and deposition in port areas are calculated in five distinctive scenarios:

1. Baseline: visiting intensity of various types of ships in base year 2010.
2. Shore power: supply of shore power to tankers and bulk carriers in both ports.
3. Energy port: extra visits of large vessels in Eemshaven port.
4. Offshore port: 50% extra emissions by offshore vessels in Eemshaven port.
5. Chemical port: extra chemical-based ship visits in Delfzijl.

Emissions are calculated by the EMS methodology for calculating ship emissions in the Netherlands. Concentrations and depositions are calculated by the OPS atmospheric transport model.

Emission reduction by shore power at the actual visiting intensity is most effective for tankers in Delfzijl. The increase of ship visits in Eemshaven port energy and offshore port scenarios results in significantly higher emissions. In the Delfzijl chemical port scenario emissions are increasing too. However, the Eemshaven port energy and offshore scenario are both highly probable to take place. Combining these scenarios more than doubles the emissions relative to the base scenario. A hypothetical supply of the vessels in these scenarios with shore power will reduce most extra emissions. Especially in Eemshaven port, the emission reduction potential by shore power is substantial.

NO_X and SO_2 concentrations and depositions are calculated in an area of 5 km x 5 km. The trend in the calculated NO_X and SO_2 concentrations and depositions in the scenarios is similar to the trend in the emissions. Significant dispersion of the substances is limited to the areas adjacent to the emission sources. In all scenarios concentrations originating from shipping in the ports contribute significantly to the background concentration in the port areas. The calculated values do not exceed NO_X or SO_2 concentration limits for the protection of nature and human health.

Samenvatting

Scheepvaart levert een belangrijke bijdrage aan de luchtvervuiling in havens en in kustgebieden. In deze studie wordt de bijdrage uitgerekend van NO_X en SO_2 emissies door de scheepvaart aan de lokale luchtvervuiling in het gebied rond Delfzijl en rond de Eemshaven. Dit is gedaan om de relevantie van scheepvaart als lokale luchtvervuiler te bepalen en om te kijken of walstroom een goede mogelijkheid is voor emissiereductie. De jaarlijkse emissies van NO_X en SO_2 en de resulterende concentraties en depositie van deze stoffen in het gebied, worden uitgerekend in verschillende scenario's:

1. Basisscenario: scheepvaartsituatie in de havens in 2010.
2. Walstroom: wanneer tankers en bulkcarriers worden aangesloten op walstroom.
3. Energiehaven: extra bezoek van grote schepen in de Eemshaven.
4. Offshorehaven: 50% extra emissies door meer offshoreschepen in de Eemshaven.
5. Chemiehaven: extra bezoek van chemie gebonden schepen in Delfzijl.

De emissies worden uitgerekend met behulp van de EMS methodiek die in Nederland gebruikt wordt om scheepsemissies uit te rekenen. De concentratie en depositie worden uitgerekend met behulp van het atmosferisch transportmodel OPS.

Bij de huidige intensiteit van scheepvaart is de meeste emissiereductie als gevolg van walstroom mogelijk in Delfzijl. De groei in scheepsbezoek in de Eemshaven energie- en offshore scenario's leiden tot een significante emissietoename. Dit is ook het geval voor Delfzijl in het chemiehavenscenario. Echter, het energiescenario en het offshorescenario hebben beide een grote waarschijnlijkheid en vinden beide plaats in de Eemshaven. Wanneer de scenario's worden gecombineerd, zullen de emissies meer dan verdubbelen. De meeste van de extra emissies zullen worden vermeden wanneer de extra schepen in de scenario's worden aangesloten op walstroom.

In het bijzonder in de Eemshaven, heeft deze studie laten zien dat er een significant reductiepotentieel is.

De NO_X en SO_2 concentraties en depositie zijn uitgerekend voor een gebied van 5 km bij 5 km. De concentratie en depositie trend in de scenario's is dezelfde als de trend in emissies. Significante verspreiding van de stoffen is beperkt tot de gebieden in de directe omgeving van de emissiebronnen in de havens. De concentraties als gevolg van scheepsemissies dragen in alle scenario's significant bij aan de achtergrondconcentratie in de havens. Dit laat zien dat de scheepvaart in een haven een belangrijke luchtvervuiler is. Er worden echter geen concentratienormen overschreden.

Abbreviations

EMS	Emission registration and Monitoring Shipping
GT	gross tonnage
IMO	International Maritime Organization
ktonnes	kilo tonnes
LNG	Liquefied Natural Gas
mt	metric tonnes
Mtonnes	mega tonnes
$\mu g\ m^{-3}$	micrograms per cubic meter
mole $ha^{-1}\ yr^{-1}$	mole per hectare per year
N	nitrogen
NGO	non-governmental organization
NO_X	nitrogen oxides
OPS	Operational Priority Substance
PM	particulate matter
PSSA	Particularly Sensitive Sea Area
RD	Rijksdriehoek (Dutch Cartesian system)
RIVM	Dutch National Institute for Public Health and the Environment
RoRo vessel	Roll on/Roll of vessel
S	sulfur
SO_2	sulfur dioxide
WGS84	World Geodetic System 1984; international standard spherical reference datum for charts and chart projections

Executive summary

Ship air pollution

Shipping contributes significantly to air pollution by the emissions of NO_X and SO_2. Ships have a high fuel demand as a result of continuous use of main engines for propulsion and auxiliary engines and boilers for electricity and heat production while in port. The dominant fuel type is residual fuel oil. Residual fuel oils have high sulphur and nitrogen contents compared to distillate fuels like gasoline and gasoil.

The highest exposure levels of air pollution by shipping are found in ports and near ports, because 80% of the world fleet is positioned in ports or navigating in coastal areas. Many people live in port cities or coastal areas. Many fragile ecosystems are located in coastal areas and risk to be affected by ship air pollution.

The port authority “Groningen Seaports” manages two commercial shipping ports in the Northern Netherlands: Eemshaven port and the port of Delfzijl. These ports are located adjacent to the fragile Waddensea area. An assessment of ship air pollution in their ports is crucial to Groningen Seaports, as shipping intensity in Eemshaven port is expected to increase in the near future. Groningen Seaports has the self-imposed mission to work towards sustainability of the activities in their ports in oncoming years.

Air pollution research

The aim of this study is

1. to quantify ship emissions and their contribution to local atmospheric air pollution in the Eemshaven-Delfzijl area,
2. to evaluate the relevance of shipping as a source of pollution,
3. to evaluate whether shore power as an emission reduction measure is effective in medium size ports like Eemshaven port and Delfzijl.

The emissions and resulting concentrations and deposition are calculated in five distinctive scenarios:

1. Baseline: visiting intensity of various types of ships in base year 2010.
2. Shore power: supply of shore power to all tankers and bulk carriers visiting the ports based on scenario 1.
3. Energy port: extra visits of large vessels in Eemshaven port supplying power plants and oil storage terminal.
4. Offshore port: 50% extra emissions by offshore vessels as result of increasing offshore construction activities in Eemshaven port.
5. Chemical port: extra visits of vessels in Delfzijl after potential increase of chemical-based industrial activities in Delfzijl.

Shore power is the best available emission reduction technology for ports. Shore power is therefore used in scenario 2 as reduction measure. Shore power supplies the electricity demand of a vessel when berthed, preventing the emissions from the vessels auxiliary engines.

The energy port scenario 3 and offshore port scenario 4 are both very probable to take place, because the oil terminal is actually in operation, the power plants are in construction. Offshore vessel visit frequency is also rising, due to the increased wind farm construction activities at the North Sea.

Emission inventory

The annual emissions are calculated for individual vessels of various ship types (table 1) visiting the ports. The emissions during sailing in the ports are distinguished from the emissions during hoteling. Emissions are calculated by the Emission registration and Monitoring Shipping protocol. This methodology is used by various Dutch research institutes to calculate emissions from ships in the Netherlands and on the Dutch continental shelf.

Table 1; ship types evaluated in this study.

Ship type
Tankers
Bulk carriers
Container vessels
General cargo vessel
RoRo vessels, cruise vessel, ferries
Reefers
Other types; tugs and offshore related vessels
Inland vessels

The supply of shore power to tankers and bulk carriers results in annual emission reductions in both ports (table 2). The potential emission reduction at the actual visiting intensity is largest in Delfzijl. The reduction in Eemshaven port is only minor. The increase of ship visits in the Eemshaven port scenarios results in significantly higher annual emissions, with a relatively low ship visit frequency increase (table 3). Emissions will increase even more when the big vessels in the energy scenario are substituted by smaller ships with less draught to be able to reach Eemshaven port. The increase in visiting frequency in Delfzijl in the chemical scenario is much higher, while the increase in annual emissions is significantly lower.

The energy and offshore scenario both regard to Eemshaven port. When these scenarios are combined the emission increase is substantial (figure 1). In these two scenarios and their combination, a hypothetical supply with shore power will reduce most of the extra emissions. The largest emission reduction is reached in the offshore scenario. So, especially in Eemshaven there is a significant emission reduction potential.

Table 2; emission trends in Delfzijl in the four scenarios including ship visits in Delfzijl.

	Base scenario	Shore power bulk carriers	Shore power tankers	Chemical port
NO_X (mt)	60.4	58	49.3	72.8
SO_2 (mt)	27.3	26.3	20.8	35
Ship visits	3719	3719	3719	4519

Table 2; emission trends in Eemshaven port in the four scenarios including ship visits in Eemshaven port.

	Base scenario	Shore power bulk carriers	Shore power tankers	Energy port	Offshore port
NO_X (mt)	64.2	62.2	64.1	123.6	80.1
SO_2 (mt)	24	23.1	24	54.7	28.6
Ship visits	2931	2931	2931	3843	N/A

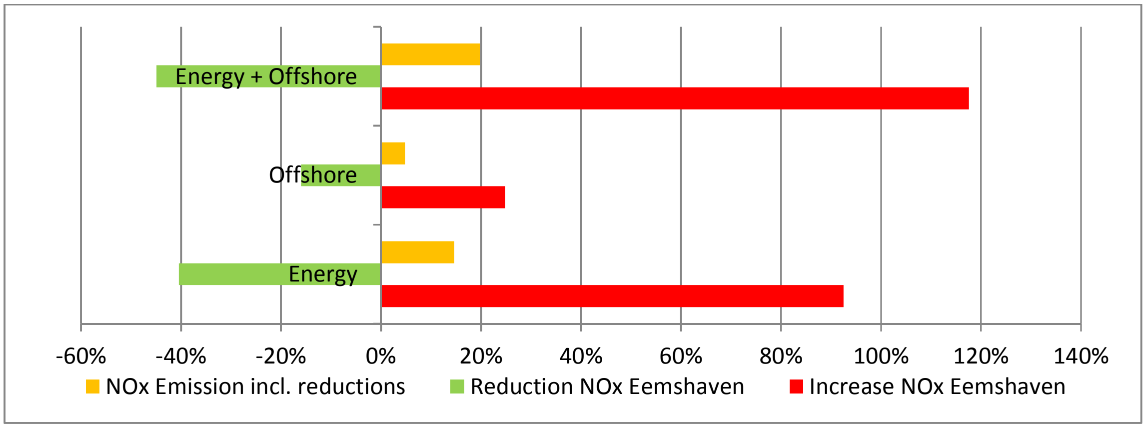
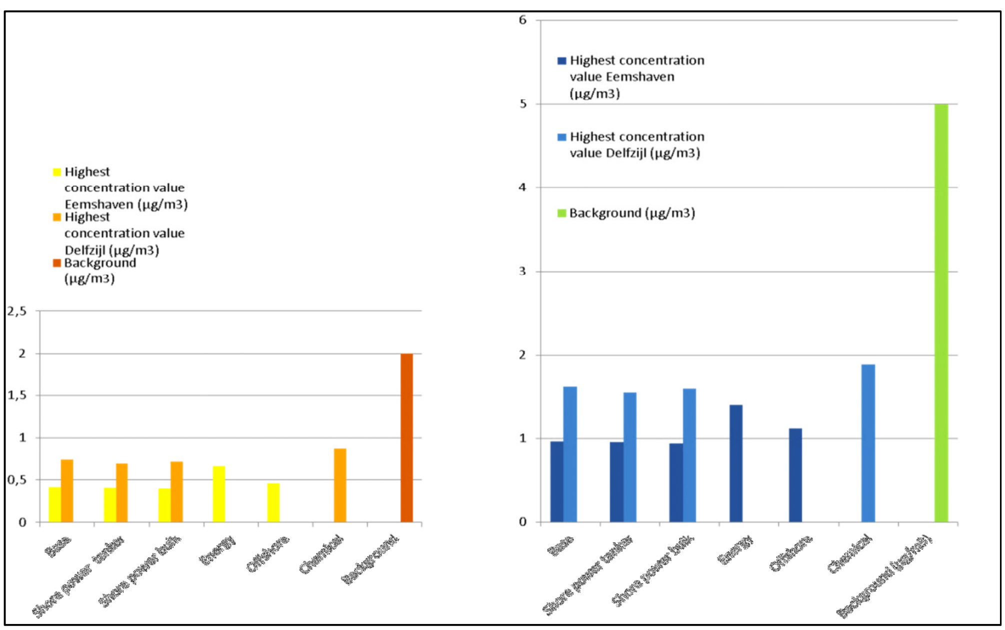


Figure 1; emission trend in energy and offshore scenario. The red bar represents the relative annual NO_X emission increase with respect to the baseline scenario. The orange bar represents the relative annual NO_X emissions increase with respect to the baseline scenario when the ships in the scenarios are supplied with shore power. The green bar represents the relative annual NO_X emission reduction of the total annual NO_X emissions in the specific scenario when the extra ships are supplied with shore power.

Air pollution dispersion

To calculate the dispersion and deposition of nitrogen and sulphur oxides the Operational Priority Substance (OPS) atmospheric transport model is used. EMS emission output is used as input for OPS calculations. The model delivers the annual average concentration and deposition of substances at specified positions, based on annual average meteorological data. By its annual approach, OPS is not suitable to model concentration peaks as a result of peaks in ship visits.

The trend in the calculated NO_X and SO_2 concentrations and depositions in the scenarios is similar to the trend in the emissions (figures 2 and 3; tables 3 and 4). PM emissions were also modelled and turned out to be insignificant. Modelling was restricted to a 5 km x 5 km square area; highest concentration values refer to the direct areas adjacent to the emission sources within the 5 km x 5 km area.



Figures 2 and 3; comparison of OPS results with the background values. The results presented in these figures are the highest SO_X (yellow) and NO_X (blue) concentration values in the five scenarios.

Table 3; annual N and S deposition in Delfzijl in the scenarios. The values are in mole ha^{-1} yr^{-1}.

	Base scenario	Shore power bulk carriers	Shore power tankers	Chemical port
N	14.4	14.2	13.8	16.7
S	29.9	29.1	28.1	35.5

Table 3; annual N and S deposition in Eemshaven port in the scenarios. The values are in mole ha^{-1} yr^{-1}.

	Base scenario	Shore power bulk carriers	Shore power tankers	Energy port	Offshore port
N	12.4	12.1	12.4	19.1	14.5
S	16.8	16.5	16.8	26	18.8

In all scenarios the concentrations originating from shipping in the ports contribute significantly to the background concentration in the port areas. So shipping within the port areas is an important contributor to local air pollution. The calculated values do not exceed NO_X or SO_2 concentration limits for the protection of vegetation. The modelled concentrations are fraction of the limits levels (NO_X: 30 µg m^{-3}; SO_2: 20 µg m^{-3}).

Ship emissions contribute to about 10% to the annual background deposition in the port areas. The background deposition of nitrogen oxides in the Northern Netherlands has already reached harmful levels that are harmful for salt marshes. The mud-flats area outside the Waddensea dikes, including the area adjacent to the ports is defined as protected salt marsh area. Each extra amount of deposition will have more negative effects on this area.

Recommendation

The emissions in the near future can be reduced significantly when shore power is implemented in Eemshaven port. With emission reduction the already affected Waddensea area will be benefit mostly.

When implementing shore power as emissions reduction measure, the port authority should be aware of the risk of shifting the air pollution problem. This would be the case when the shore power is produced by the fossil fuel based power stations in Eemshaven port, thus shifting the emissions from the vessels to the power plant. Electricity supplied by renewable sources (wind power, photovoltaic) is recommended for all connections, for these sources are emission-free.

Chapter 1: Introduction

1.1 Air pollution by shipping

The transhipment of cargo worldwide has a significant contribution to anthropogenic air pollution. Within the transport sector shipping is the number one modality for international bulk transport (Christiansen *et al*., 2004; IMO, 2009a). Shipping is the most fuel efficient modality for transport (in energy consumption per tonne). However, the absolute contribution of shipping to global warming and air pollution is rather high (Walsh and Bows, 2012; Chang, 2012). In spite of this, shipping is shielded from emission mitigation measures until recently (Lai *et al*., 2011), contrary to other transport modalities and industries.

In absolute terms, ships have a high energy demand resulting in large emissions to the atmosphere (table 1.1; Cofala, *et al.,* 2005; EAE, 2008; IMO, 2009b; Wright, 2000). The main energy source of the shipping industry is residual (heavy) fuel oil (HFO; Van Maanen, 2000). Residual fuel oils have high sulphur and nitrogen contents (Cooper, 2003) compared to distillate fuels like gasoline and gasoil.

Table 1.1; contribution of shipping to anthropogenic atmospheric emissions in 2007 (EAE, 2008; IMO, 2009b;).

	CO_2 emissions (Mtonnes)	Percentage of total CO_2 emissions	NO_X emissions (Mtonnes)	Percentage of NO_X emissions	SO_2 emissions (Mtonnes)	Percentage of SO_2 emissions
Total shipping	1046	3.3 %	25	19%	15	11%
Int. shipping	870	2.7 %	20	15%	12	9%

Recently the IMO started to develop far-reaching legislation concerning fuel efficiency and emission reduction measures for the shipping industry (IMO, 2009b). A drawback in applying energy efficiency on vessels is the lifetime of a ship. Ships have an average lifetime of 25 years, which is far longer than road-based transport modalities. This is an obstacle in the implementation of reduction techniques on board; for example the installation of more efficient engines. Most ships will sail during their entire lifetime with machinery installed while building. Retrofitting of ships is regarded as difficult and costly in time and money.

1.2 Air pollution effects

Particulate matter, NO_X and SO_2 are substances causing various environmental effects on regional and local scale (table 1.2; Guicherit, 1998; Matthias *et al*., 2010).

Table 1.2; effects of air pollutants (Bouma *et al.*, 2005; Doney *et al.*, 2007; Genc *et al.*, 2012; Kaiser *et al.*, 2005; McKinney, Schoch, & Yonavyak, 2007; Phoenix *et al.*, 2012; Stolt *et al.*, 2011).

Substance	Environmental effects	Affecting
NO_X	Eutrophication Acidification Forming of photochemical oxidants and particulate matter (smog)	Nature Nature Health and materials
SO_2	Acidification Forming of particulate matter	Nature Health
PM	Dust Smog	Health Health and materials

Air pollution of maritime origin is concentrated in port areas. At any time, about 80% of the world fleet is harboured or navigating somewhere near the coast (Balkanski *et al*., 2010; Deniz *et al*., 2010). Relatively high concentrations of nitrogen oxides are found along main shipping routes (Lawrence &

Crutzen, 1999). In port areas concentrations can be increased by an additional contribution from cargo handling equipment, road transport and industries (Aldrete *et al*., 2007).

1.3 Emission reduction incentives

In order to reduce the environmental and health effects of the emission of air pollutants by shipping, several measures are of will be imposed:

1. Actual legislation concerning NO_X and sulphur emissions presented in MARPOL Annex VI (Annex 4 of this report; IMO, 2011a). Special NO_X emission requirements apply to vessels built on or after 1 January 2010, becoming stricter for newer vessels (regulation 13 of MARPOL Annex VI, Annex 4 of this report).
2. In order to reduce sulphur emissions special emission control areas (SECA's) are designated in which only low-sulphur fuels are allowed (figure 1.2). The North Sea including the English Channel and Dover Strait, the Baltic Seas, and seas off the Californian coasts are designated as special emission control areas. At present a fuel S-content of maximum 1% by weight is allowed in these areas. In the future this maximum level will become stricter. Fuel S-content below 0.1% are allowed to be combusted in European ports (EU, 2005). Common marine fuels have an average sulphur content of 2.7% by weight (Cooper, 2003), but it may contain sulphur up to 5% by weight (Van Maanen, 2000).

Figure 1.2; existing Special Emission Control Areas and possible new SECA areas.

3. From January 2013 onward new MARPOL regulations will enter into force (IMO, 2011b). This set of regulations demands vessels to improve the on-board energy efficiency in order to reduce atmospheric emissions. Vessels have to comply with an energy use and emission baseline. The possibilities for vessels to reach the baseline are embedded in the design for new ships and in their operations (IMO, 2009b).

Port authorities can respond by taking measures to reduce shipping emissions in their areas. With the growing quest of society for a cleaner environment, ports should act in adopting environmental policies to support their account to society and their competitiveness to other ports (Lai *et al*., 2011).

Ports can play a key role in sustainable development of the shipping industry. The shipping industry needs incentives in adopting energy saving and sustainability enhancing practices. Of all actors related to shipping industry, ports can deliver a substantial part of the necessary incentives to the industry. With incentives from ports in general, not only shipping industry would be addressed, but other port-related emitters as well.

Ports authorities can apply several incentives to stimulate sustainable shipping:

1. Port can give a port fee discount to vessels with high energy efficiency and low environmental impact, stimulating measures within the shipping and shipbuilding industries.
2. The facilitation of natural liquefied gas (LNG) as vessel fuel. The combustion of LNG results in reduced emissions as compared to fuel oils (Kumar *et al*., 2011). The facilitation of LNG by ports is attractive for vessels operating on gas to visit the ports with gas supply. Another potential clean fuel is a mix of gasoil and ethanol (Boretti, 2012).
3. The supply of power from shore to berthing vessels. This measure has a direct influence on the local atmosphere (Yang *et al*., 2011), because shore power will reduce the emissions from auxiliary engines and boilers in port. Berthing ships produce their own power and heat for cargo handling and accommodation reasons. Power required during berthing is produced by auxiliary diesel engines. Boilers are used for heat. Both are the main source of ship-related emissions in ports (Cooper, 2003). Instead of producing their own power the ships are connected to an external power source (figure 1.2). Shore power supply results in substantial reduction of emissions from vessels berthing in port. Shore power offers the opportunity for renewable energy supply.

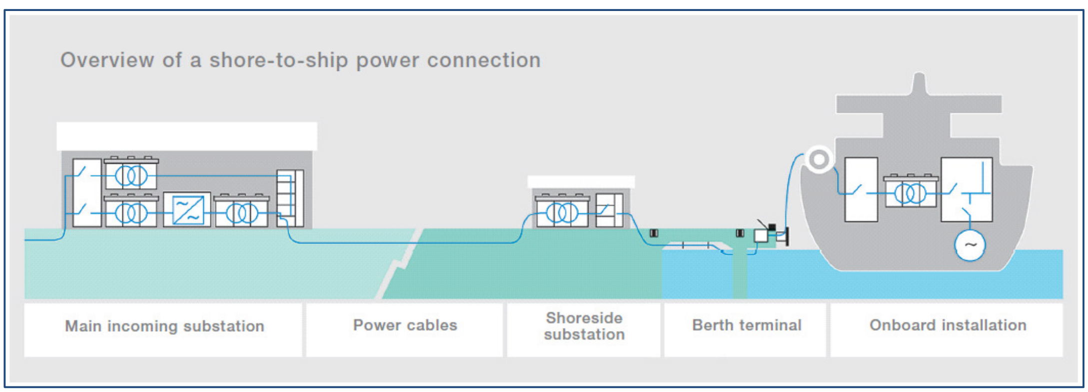


Figure 1.2; shore power installation layout for a hoteling vessel (ABB, 2010).

The ports in this study are medium size ports with strong regional significance. In medium size ports environmental incentives for the shipping industry can be implemented on a small scale as compared to main ports. Medium size ports can act as pilots in incentive implementation to show how ports can operate in improving the local environment and reduce air pollution by shipping.

Chapter 2: Study aim and relevance

2.1 Aim

This study aims

1. to quantify ship emissions and their contribution to local atmospheric air pollution in the Eemshaven-Delfzijl area,
2. to evaluate the relevance of shipping as a source of pollution,
3. to evaluate whether shore power as an emission reduction measure is effective in medium size ports like Eemshaven port and Delfzijl.

Emissions are quantified for various ship types in five distinctive scenarios. The emission impact of shore power supply to relevant ship types is evaluated for the actual ship visiting frequency (2010) as well as for scenarios of future expansion of the ports. The contribution of ship emissions to NO_X, SO_2 and PM concentrations in the port areas is quantified in order to evaluate its significance to background concentration and to EU limit concentration values.

2.2 Clean North Sea Shipping

The current European Interreg IVB Clean North Sea Shipping project (CNSS, 2012) is "focusing on emission and greenhouse gas reduction from ships, using studies to reveal the status of air quality in ports and surrounding areas". In the project several partners (ports, businesses, regions, public authorities, NGOs and research institutes) are aiming to reduce global warming and air pollution by developing and implementing environmentally sound, cost-effective concepts and practical solutions in line with upcoming standards.

2.3 Groningen Seaports

Groningen Seaports, the port authorities of two Dutch commercial ports Eemshaven port and Delfzijl are members in the Clean North Sea Shipping project. Main port activities are general cargo, chemical industry and energy based industry. Groningen Seaports want to present themselves as energy and green ports and seek to find measures to reduce the environmental impacts from port activities. The port is Ecoports certified:

"Groningen Seaports acquired the prestigious Ecoports certificate in 2006. The Ecoport certificate is granted to ports which continuously improve their environmental policies and the coherence with the natural surroundings of the ports. The environment is an integral part of the business operations of Groningen Seaports (Port Handbook)."

The ambition of Groningen Seaports is to be the most important green port and industrial area of the Northern Netherlands in 2030. According to the targets, emissions of CO_2 and other pollutants will be reduced by 60% compared to 2015-levels. Consumed electricity will be 100% renewable. Emission reduction measures considered by Groningen Seaports are the implementation of shore power for berthed ships (ocean going and inland shipping) and the facilitation of LNG at the ports to attract cleaner vessels. The port authorities give port dues discount to vessels participating in the Environmental Ship Index; *i.e.* vessels that perform better in reducing air emissions than required by the current emission standards of the IMO. The emission reductions will take place in the background of a transhipment and ship visiting frequency increase.

2.4 Reading guide

In chapter 3 the emission and dispersion calculation methodologies are elaborated. In this chapter the scenarios dealing with different shipping intensities are introduced. In Chapter 4 the calculated results are presented for the various scenarios in terms of emissions, concentrations and depositions. Chapter 5 deals with the evaluation of the results to the area of Delfzijl and Eemshaven port. In this section the scenarios are reviewed relative to the baseline scenario. Chapter 6 presents the conclusions of this study. In Chapter 7 the calculation methodologies and assumptions made in the study are discussed, followed by recommendations in Chapter 8. The recommendations concern emission calculation methodology and air pollution modelling as well as recommendations to Groningen Seaports concerning shore power.

Chapter 3: Methodology and materials

3.1 Research area

The port of Delfzijl and Eemshaven port are commercial ports, situated in the north of the Netherlands on the western shore of the Ems estuary (figure 3.1). On the opposite shore, in Germany, lies Emden with its commercial ports. The Eemshaven port is an artificial port started to be developed in the 1970s (figure 3.2). The port of Delfzijl belongs to the town of Delfzijl. The ports are located approximately 15 kilometres apart.

Figure 3.1; Ems estuary with port of Delfzijl and Eemshaven port on the western and north-western shore. Maps retrieved from Googlemaps.

Figure 3.2; layout of Delfzijl and Eemshaven port. The Eemshaven port consists of four tidal deep sea basins. The port of Delfzijl consists of a tidal basin and two non-tidal inland docks and berths along the Ems canal to Groningen. The tidal basin and the non-tidal docks and canal are separated by a lock. Maps retrieved from Googlemaps.

Both ports together are the sixth biggest commercial ports in the Netherlands (table 3.1). The total transhipment in 2011 was 8052 thousand tons (table 3.2). During the years prior to 2009 the ports, especially Eemshaven port, have grown. The 2009 dip results were caused by the financial crisis at that time. However, the visit frequency trend in the ports is growth, especially in Eemshaven ports, with the new power plants and expected increase in offshore traffic.

Table 3.1; cargo transhipment in the six biggest ports in The Netherlands in 2011 (Rijksoverheid, 2012).

	Total cargo (x1000 mt)
Rotterdam	869 100
Amsterdam	74 718
Zeeland Seaports	34 967
Moerdijk	21 767
Velsen/IJmuiden	17 658
Groningen Seaports	8 052

Table 3.2; transhipment of goods in recent years in the port of Delfzijl and Eemshaven port (Groningen Seaports, 2012).

	2011	2010	2009	2008	2007	2006
Transhipment by ocean going shipping (x 1000 mt)	3134	3380	2904	3310	3130	2929
Transhipment by inland shipping (x 1000 mt)	4917	4242	3987	4673	7672	4791
Total transhipment (x 1000 mt)	8052	7622	6899	7982	7802	7721

The exposure to air pollution in the area can be significant. The two ports are situated in the Ems estuary on the shores of the particularly sensitive (PSSA according to IMO criteria) Waddensea salt marsh area (Bakker, *et al*., 2005). The ports are located near the coastal towns of Delfzijl and Emden, the town of Appingedam, the adjacent rural coastal areas of the Dutch province Groningen and the German Ost Friesland area, and the touristic Waddensea island Borkum (figure 3.3). The number of people living in these areas (without tourists to Borkum) is around 174 000 (LSKN, 2011; Provincie Groningen, 2012).

Figure 3.3; Eemshaven port seen from the island of Borkum (photograph via Flickr (Sicco2007)).

3.2 Scenarios

Five scenarios with variable emissions – *e.g.* more ship visits or emission reduction measure applied – are evaluated in this study. For each scenario the emissions of NO_X, SO_2 and PM by shipping are calculated. Subsequently the contribution of shipping related emissions to concentrations and deposition in the port area is calculated. The scenarios that are dealt with are:

1. Baseline scenario; situation in 2010
2. Shore power; for ship types most influencing the emission trend in baseline scenario 1
3. Energy port; increase of shipping related to Eemshaven port newly built power plants and oil terminal
4. Offshore port; increase of offshore related shipping in Eemshaven port
5. Chemical port; increase of chemical industry Oosterhorn related shipping in Delfzijl

3.2.1 Scenario 1; baseline

Scenario 1 reflects the shipping intensity in various ship types in Eemshaven port and Delfzijl in the reference year 2010. The other scenarios are adaptations of this scenario.

3.2.2 Scenario 2; shore power

From scenario 1 the ship types with highest emissions are selected to be virtually supplied by shore power to substitute power supply by the auxiliary engines. The results show whether shore power supply for this vessel type is adequate and significant in reducing emissions in Delfzijl and Eemshaven port.

Shore power is modelled by eliminating the oil demand for the auxiliary engines of the selected ship type. This approach assumes that every ship can be connected to shore power. Among possible reduction measures shore power is the easiest to implement. The use of low sulphur fuel is already proven (Bailey & Solomon, 2004) and does not reduce NO_X and greenhouse gas emissions. The use of LNG as marine fuel is in an early stage of implementation; LNG entails more safety risks (Astbury, 2008) and retrofitting existing ships is very costly.

3.2.3 Scenario 3; energy port

In the near future ships with an increased volume will visit the Eemshaven port when a new oil terminal and power stations will become operational. In scenario 3 the effects of these planned ship visits are modelled. These vessels have volume size of 20 000 to 40 000 GT (table 3.3; Koolstra *et al.*, 2012). The vessels in this scenario will have an extra contribution of pollutants to the local atmosphere as result of their size. Their visits are added to the ships visiting the ports in 2010.

Table 3.3; expected additional vessels to arrive when new industries in Eemshaven port become operational.

	Deadweight (mt)	Volume (GT)	Extra ship visits
Handysize	30 000	20 000	175
Handysize	30 000	20 000	30
Panamax	60 000 – 80 000	40 000	7
Inland Shipping			700

A variant of scenario 3 investigates how ship emissions would develop when these handysize and panamax vessel are substituted with ships having smaller cargo capacities (table 3.4). Total volume for tankers remains 880 000 GT and total volume for bulk carriers remains 3 500 000 GT. This scenario is relevant because of the current debate about the environmental effects of extensive dredging in the fairway to Eemshaven port (Koolstra *et al*., 2012). The fairway needs to be deepened for the handysize and panamax vessels to reach Eemshaven port. Until then smaller vessels substitute the originally planned vessels. Bigger ships have higher fuel efficiency per volume unit than smaller ships, which is the advantage of scale (Kendall, 1972; Van Maanen, 2000). The smaller vessels will have more emissions per volume unit. There will also be more ship movements in the port area when smaller ships visit the port.

Table 3.4; sizes of substituted smaller vessels in energy scenario.

	Volume (GT)	Extra ship visits
Tanker	3333	12
Tanker	5000	12
Tanker	7000	36
Tanker	8000	66
Bulk Carrier	8000	410
Bulk Carrier	10 000	22

3.2.4 Scenario 4; offshore port

Scenario 4 deals with increased visit intensity in Eemshaven port by offshore related shipping and ocean going tugs. An increase in offshore related traffic in Eemshaven port is likely to occur. The port has the ambition to play a key role in the energy market in the Netherlands and as supply port for wind farms in the North Sea.

In this scenario the emissions from tugs and other offshore vessels are increased with an arbitrary 50% of 2010 levels as an indication of the effects in increase in offshore activities. How many vessels eventually will visit the port in the near future is unforeseen.

3.2.5 Scenario 5; chemical port

Scenario 5 deals with a hypothetical growth of industry related shipping in Delfzijl in the Oosterhorn area (figure 3.4). In this scenario the ship visit frequency is increased with 400 seagoing vessels with average volume of 3000 GT and 400 inland vessels compared to the situation in 2010 (table 3.5).

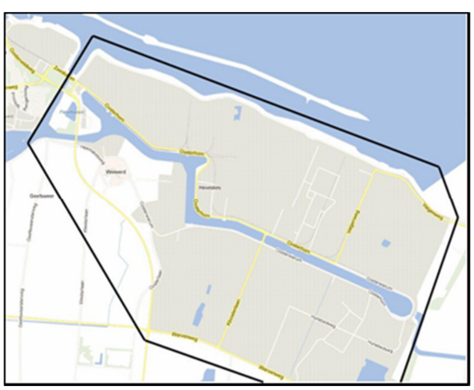


Figure 3.4; Oosterhorn industrial area. The area consists mainly of chemical and metal industry. Map retrieved from Googlemaps.

Table 3.5; expected vessels to arrive cumulative to the situation in 2010 with new industrial developments in Delfzijl.

	Volume (GT)	Annual extra ship visits
Tanker	1000	80
Tanker	2500	80
Panamax	4000	80
General cargo	2000	80
General cargo	2500	80
Inland vessels		400

3.3 Methodology steps

The calculation of the contribution by shipping to the local air pollution consists of two steps performed in each scenario:

1. inventory of the emissions by analysing individual ship visits in 2010, for evaluating the emission trends and reduction potentials; and
2. modelling the dispersion of the emissions across the area by an atmospheric transport model evaluating the contribution of the emission to background concentration and deposition levels as well to evaluate whether EU limits are violated.

3.3.1 Emission inventory

The inventory is made for distinguished ship types per month in 2010 (table 3.6, figures 3.5a – 3.5h). The visiting frequency and emission factor of a particular ship type per month compared to the total monthly emissions indicates which ship type dominates the total emissions in the ports and shows where reduction measures will have the most potential gains.

Table 3.6; ship types in EMS protocol included in the monthly emission inventory.

Ship type
Tankers
Bulk carriers
Container vessels
General cargo vessel
RoRo vessels, cruise vessel, ferries
Reefers
Other types; tugs and offshore related vessels
Inland vessels

Figure 3.5a

Vessel type:	Bulk carrier
Gross tonnage:	40 224
Length:	225m
Beam:	32 m
Draught:	14m

Figure 3.5b

Vessel type:	Oil/chemical tanker
Gross tonnage:	5642
Length:	124 m
Beam:	17 m
Draught:	5.5 m

Figure 3.5c

Vessel type:	Container ship (feeder)
Gross tonnage:	5067
Length:	119 m
Beam:	20 m
Draught:	6.5 m

Figure 3.5d

Vessel type	Reefer
Gross tonnage:	3968
Length:	95 m
Beam:	16 m
Draught:	5 m

Figure 3.5e

Vessel type:	RoRo/passenger
Gross tonnage:	1859
Length:	78 m
Beam:	**12** m
Draught:	3.2 m

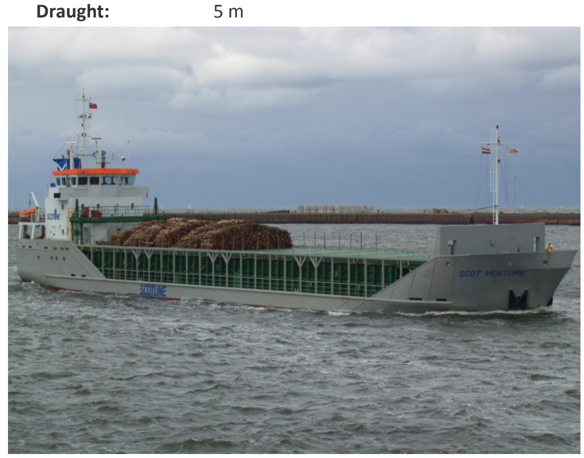


Figure 3.5f

Vessel type:	General cargo
Gross tonnage:	2602
Length:	90 m
Beam:	**14** m
Draught:	5 m

Figure 3.5g

Vessel type:	Tug (other ships)
Gross tonnage:	342
Length:	**32** m
Beam:	10 m
Draught:	5.5 m

Figure 3.5h

Vessel type:	Inland vessel
Gross tonnage:	N/A
Length:	**75** m
Beam:	**8** m
Draught:	3.5 m

3.3.2 Emission calculation sheet

The inventory is set up to be suitable to give input for the scenarios and output in terms of the contribution of the individual ship type to the total emissions of NO_X, SO_2 and PM emissions in Delfzijl and Eemshaven port.

To determine the scenarios on a detailed spatial scale, data on scenarios specific movements and behaviour of each ship in the ports is needed. The approach for the inventory is bottom-up. Emissions determined in this approach are placed within a spatial context (Paxian *et al*., 2010) and a detailed emission inventory can be reached. Emissions are calculated based on shipping activity data and properties, like ship type, size, speed, engine power, and ship emission factors. On the contrary, a top down emission calculation methodology is based on bunker sales (amount of bunker fuel sold to the shipping industry) as measure for exhaust gas emissions (Deniz *et al*., 2010), resulting in a coarse emission estimation excluding specific spatial shipping movements and energy use. For this study a top-down approach would be too coarse to be suitable in the scenario analysis.

Shipping behaviour in this study is differentiated into two activity stages of a vessel in the ports:

1. Hoteling stage
2. Sailing stage

The emissions during the hoteling stage, which is the stage a vessel is berthed, depend mainly on the duration the vessels are berthed. Sailing emissions depend mainly on the route length between port entrance and their berth of destination. Sailing emissions are calculated only within the port areas and not on the Ems River. This study focuses on the emission within the ports and on the measures that can be taken within the ports. The fundamental responsibility of the port authorities is restricted to the area within the port limits.

For several shipping activities the forthcoming emission factors are known. However, the emissions during manoeuvring in port or in a lock are too complex to model (Erbink *et al*., 2011). Essential data on manoeuvring time and time in the lock are lacking, so these two stages are excluded from the emission inventory. Manoeuvring, however, is a major activity of ships during which emissions are probably high during a short time because of high power demand. When navigating in a lock, ships have to manoeuvre and use the main engine delivering extra emissions in a restricted area. The emissions from ocean going shipping in the inventory might therefore be underestimated.

Inland vessels emissions are estimated in this study. Data to calculate emissions from individual vessels is lacking. Essential data is installed engine power and fuel use by these ships. In 2010, more inland vessels visited the ports than ocean going vessels. Inland shipping is therefore a major emission source in the ports.

Inland shipping emissions are estimated comparing the deadweight of the inland vessels to the deadweight of ocean going shipping. Inland vessels have an average deadweight of 50% as compared to ocean going vessels. Therefore inland vessels are assumed to have a shorter hoteling time in the port and less hoteling emissions per ship. There were about 1200 inland vessels more than ocean going vessels visiting the ports in 2010. Inland vessels have lower emissions per energy unit than ocean going vessels (Denier van der Gon & Hulskotte, 2010). Inland shipping emissions in the two ports are assumed to be 50% of the annual emissions from ocean going shipping. This approach is very rough. This is not a real problem in the analysis, because the inland shipping emissions only act as input for the total emissions calculation. The reduction measures and other scenarios apply to ocean going shipping, and the necessary detailed data for these ships are available.

Fishing vessels are not included in the analysis, because data on their specific behaviour in port is lacking. Emissions from tugs aiding ocean going vessels while manoeuvring are modelled in a special way. All ocean going ships are assumed to arrive and leave on own power; from the data set it was impossible to know which vessel had tug assistance and which vessel had not. Possible tug emissions are virtually transferred to the ocean going vessels. In the "other ships" category tugs are sailing on own power in the port, modelling as well a part of pulling emissions by assisting tugs. Ships below 100 GT are excluded from the analysis.

3.3.3 EMS protocol

For the emission calculations the Dutch EMS protocol (Emission registration and Monitoring Shipping; Denier van der Gon & Hulskotte, 2010) is used. This protocol provides methodologies and emission factors for calculating emissions by shipping during sailing and hoteling. The EMS protocol supplies a bottom-up approach for emission calculation.

In the EMS approach the key factor in the ship emission calculation is gross tonnage (GT). When the GT of an individual vessel is known, the emissions of this individual vessel can be calculated.

3.3.3.1 Hoteling emissions

In the hoteling stage the emissions are based on the fuel use per GT per time unit. Fuel use is differentiated to ship types (table 4.4). Especially tankers and reefer vessels have a high fuel use caused by cargo operations (pumping and cooling/freezing).
The hoteling emissions E_h for the different pollutants are calculated by:

$$E_h = V \times F \times t \times \varepsilon$$

With:
V: ship volume in GT
F: fuel use in kg per GT hour
t: hoteling time in hours
ε: emission factor in grams per kilogram fuel

In the EMS protocol several hoteling emission factors are presented. It presents emission factors for residual fuel and for distillate fuels. The EMS further subdivides the emission factors into fuel used by two-stroke engines, four-stroke engines, and boilers. Four-stroke engines are used for port power supply (Van Maanen, 2000). In port the boiler is used for heat supply. Especially tankers use a great amount of heat for cargo heating purposes (table 3.7).
This study uses the emission factors for distillate fuels, as in 2010 the use of residual fuels during hoteling is prohibited in the EU. Distillate fuels have lower sulphur content than residual fuels. The used hoteling emission factor for SO_2 for auxiliary engines and for the boiler is 20 grams per kilogram fuel, which is a weight percentage for S of 1%.

Table 3.7; hoteling fuel use per ship type as function of gross tonnage in EMS approach. For tankers the share differs for loading and unloading. The values marked with * is the share during loading, for unloading no cargo heating needed. Heat might be needed during loading (preheating of cargo tanks).

Ship type	Fuel use (kg fuel per 1000 GT hour)	Share auxiliary engines	Share boiler
Tankers	18.4	0.55/0.35*	0.45/0.65*
Bulk carriers	2.4	0.65	0.35
Container vessels	5	0.45	0.55
General cargo vessels	5.4	0.7	0.3
RoRo vessels, cruise vessel, ferries	6.9	0.7	0.3
Reefers	24.6	0.8	0.2
Other types; tugs and offshore related vessels	9.2	1	0

3.3.3.2 Sailing emissions

In the sailing stage the emissions are based on the GT and sailing distance. Round-trip emissions E_S are calculated by the EMS protocol as follows:

$$E_S = 2 \times V \times s \times \varepsilon \times cf_e \times cf_\varepsilon$$

With:
V: ship volume in GT
s: distance sailed in kilometres
ε: emission factor in kilograms per GT kilometre
cf_e: correction factor for engine power (percentage of maximum engine power)
cf_ε: correction factor for emission factors

Sailing emissions need to be corrected for the reduced engine power when navigating in port (table 3.8), as ships do not sail on full speed in port areas. Speed within the ports was set to 9 knots, based on the author's marine experience. Sailing with reduced power decreases the combustion efficiency of engines, as most propulsion engines are designed for sailing at cruising speeds (Van Maanen, 2000). Therefore the emission factor needs to be corrected as well. Only the emissions for NO_X and PM need to be included in the correction, because the emitted amounts of these substances depend on the conditions in the engine cylinder. Sulphur emissions depend on the sulphur content of the fuel. Emissions from auxiliary engines running during the sailing stage are calculated with the same formula, but with other emission factors and without correction factors.

Table 3.8; ship sizes used in EMS protocol and used in this study. The engine load correction factor is based on the author's marine experience. The other correction factors are subtracted from Van der Tak & Cotteleer (2011).

Ship sizes (GT)	Percentage of max. engine power	ε correction factor NO_X	ε correction factor PM
100 - 499	60%	1	1
500 - 999	60%	1	1
1000 - 1599	60%	1	1
1600 - 2999	50%	1	1.01
3000 - 4999	40%	1.02	1.03
5000 - 9999	35%	1.03	1.05
10 000 - 29 999	30%	1.04	1.08
30 000 - 59 999	30%	1.04	1.08
60 000 - 99 999	30%	1.04	1.08
> 100 000	30%	1.04	1.08

The emission factors differ widely for ship types and ship size. The factor 2 in the formula refers to the times the vessel will sail in the port, one time on arrival and one time when leaving. When a ship arrives in one month and leaves in the following month, the sailing emissions in the model are dedicated to the specific months of arrival and leaving. In this case the factor 2 is not used, nor in the case of vessels that pass the ports heading for Groningen.

The values of the emission factors are referred to Denier van der Gon & Hulskotte (2010), Erbink *et al*. (2011), and Van der Tak & Cotteleer (2011).

3.4 Emission dispersion modelling

3.4.1 Operational Priority Substance model

The dispersion and deposition of the emitted substances are modelled in the Dutch Operational Priority Substances (OPS) model. OPS is an atmospheric transport model that models dispersion and deposition of emitted substances (Van Jaarsveld, 2004). The model calculates the dispersion of substances emitted by both point and area sources. The model supplies output concentrations and depositions in a grid.

The output of the model is on an annual scale. It delivers the annual average concentration and the deposition of substances at specified positions. The scale is based on the use of annual meteorology, like annual average precipitation, wind direction, and wind speed in the model. Emission data from the emission model based on the EMS protocol is used as input for the OPS model.

The model requires the heat content of the emitted exhaust gasses and the source height to calculate the dispersion grade. The heat content is linked to the amount of emitted CO_2, because the heat content in an exhaust plume is linearly related to the amount of CO_2 in the plume (Erbink *et al*., 2011). CO_2 emissions are determined like the NO_X, SO_2, and PM emissions. The emission height is chosen to be 25 meters for ocean going shipping and 6 meters for inland shipping. For most ocean going vessels the funnel height is between 20 meters and 30 meters (Denier van der Gon & Hulskotte, 2010).

To be suitable as input for the model, the emissions (in grams per second) from every vessel is spread over the entire year. This means that all ships are virtually in the ports throughout the entire year. By its annual approach, OPS is not suitable to model emission peaks when there is a peak in ship visits.

Shore power is modelled by excluding the hoteling emissions from the selected ship type in the model. This means that when a ship arrives it is directly connected to the power grid; no switching time is included.

For an in-depth description of the OPS model is referred to Van Jaarsveld (2004).

3.4.2 Emission source position

In the model the emission sources for both hoteling and sailing activities are put together in one position as a single point source because of the relative small dimensions of both ports and the annual approach of the OPS model. Distinguishing source locations within the ports is insignificant. This was proved in OPS test runs, analysing the differences in outcome between a run with all sources placed on one single point source and a run with all sources spread across the area, including the sailing emission on the line between entrance and berth. Moreover, regarding all sources placed in one position might lead to an easier interpretation of the results.

For ships that have called Eemshaven port the position is: 53° 27.1’ N; 006° 50.4’ E (WGS84). For ships that have called Delfzijl the position is: 53° 19.5’ N; 006° 56.5’ E (WGS84). The input in the model, however, is performed in RD-coordinates (Dutch Cartesian coordinate system). The RD-coordinates of the emission sources in Eemshaven port are 251409 x; 608157 y. The RD-coordinates of the emission sources in Delfzijl are 258507 x; 594225 y.

3.4.3 Area choice

The values presented by the model for the average concentration and average deposition depend on the size of the selected area in the model. The smaller the selected area, the higher the average values become (figure 3.5). In this study the area of analysis, *i.e.* the selected area in OPS, is 5 kilometres x 5 kilometres with the emission position centred. The port areas are covered by an area with these dimensions.

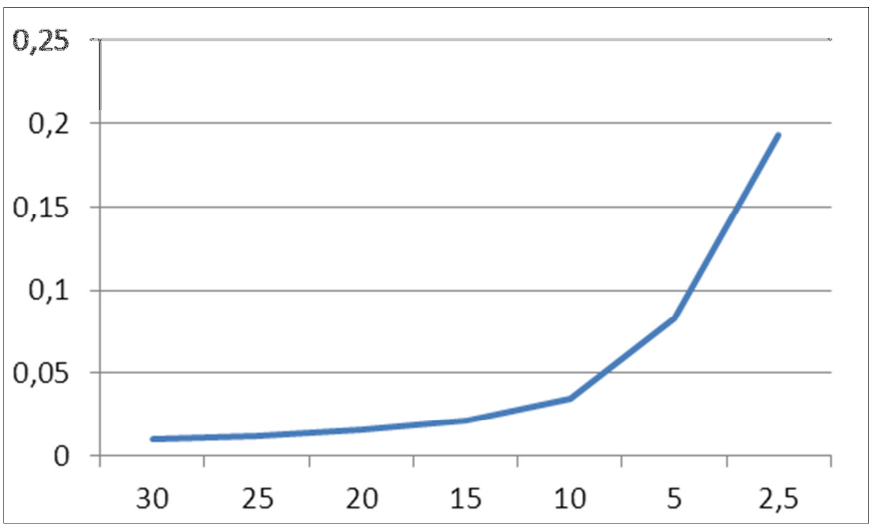


Figure 3.5; average substance concentration as function of the dimensions of a square area sides in OPS. The average concentration in OPS depends on the dimensions of the area in which OPS calculates the concentrations. The horizontal axis presents the dimensions of the sides of a square area in kilometres. The vertical axis presents the substance concentration in µg m^{-3}.

OPS does not present the actual maximum calculated values for concentration and deposition. It presents per grid cell the value in the centre of that particular grid cell. These presented values are also influenced by the selected area in the model; the grid may be shifted some hundred meters. To include possibly not-presented maximum values and to avoid coincidence, in this study the average is taken from the highest presented value and the values from the eight adjacent 500 meters by 500 meters grid cells (Annex 2). When grids are shifted the average from the presented highest value and eight adjacent values would not differ much. The average nine values are further presented in this report as maximum concentration and deposition values. However, the actual calculated highest point value is higher than presented in this study.

Chapter 4: Results

In this chapter the results of the emission inventories per scenario and the results of the scenario runs in OPS are presented. The results in this chapter are presented in tables. In Annex 1 the results from OPS are presented in graphs.

4.1 Results scenario 1; baseline

Scenario 1 deals with the actual shipping situation in 2010. In this year the total calculated NO_X emissions are 124.6 mt. For SO_2 and PM the total calculated emissions are respectively 51.4 mt and 4.3 mt. These results are differentiated for Delfzijl and Eemshaven port (table 4.1).

Table 4.1; annual emissions of shipping in Delfzijl and Eemshaven port in the base scenario. Dutch total emissions are the total emissions from ocean going vessels navigating and hoteling in port approaches and ports (Van der Tak & Cotteleer, 2011).

	Delfzijl	Eemshaven	Dutch total
NO_X emissions (kg)	60 442	64 213	22 000 000
- ***Marine***	*30 289*	*54 366*	
- ***Inland***	*30 153*	*9847*	
SO_2 emissions (kg)	27 377	24 043	9 000 000
- ***Marine***	*14 562*	*19 858*	
- ***Inland***	*12 815*	*4185*	
PM emissions (kg)	2225	2165	1 200 000
- ***Marine***	*1131*	*1808*	
- ***Inland***	*1093*	*357*	
Ship visits			
- ***Marine***	*764*	*1966*	
- ***Inland***	*2955*	*965*	
Total marine GT	$2.2 \cdot 10^6$	$4.8 \cdot 10^6$	
Total marine hoteling time (hr)	$28.1 \cdot 10^3$	$58.7 \cdot 10^3$	

The total emissions from ocean going shipping visiting Groningen Seaports is 0.39% of total NO_X and SO_2 emissions and 0.24% of total PM emissions by shipping in or near Dutch ports. National values for inland shipping are unknown for hoteling, so only sailing emissions are estimated. These values indicate that the emission levels from shipping in Eemshaven port and Delfzijl are small compared to the national shipping emissions and are of minor importance on national scale. Though, the emission levels have local importance.

4.1.1 Ship visits 2010

In 2010, 2728 ocean going vessels (table 4.2) and 3920 inland vessels visited the ports. The peak of shipping visits is found in summer, in July (figure 4.1). High emission peaks are found in March, summer, September and December. There is no one-to-one relationship between monthly ship visits and monthly emissions by ocean going shipping; compare figure 4.1 to figure 4.2.

Table 4.2; monthly ocean going ship visits frequency of Groningen Seaports in 2010 for the ship categories in this study.

	Tanker	Bulk carrier	Container	General cargo	RoRo etc.	Reefer	Other	Monthly total
January	19	6	0	58	36	4	30	153
February	12	6	0	50	36	7	24	135
March	20	5	1	72	72	7	20	197
April	14	9	0	52	103	5	38	221
May	13	5	0	57	125	10	42	252
June	16	6	0	58	134	5	42	261
July	17	9	0	59	182	8	62	337
August	13	4	0	60	179	4	53	313
September	14	6	2	52	125	8	65	272
October	12	6	0	60	112	6	48	244
November	18	5	0	59	36	5	49	172
December	16	6	0	60	42	6	41	171
Total	184	73	3	697	1182	75	514	**2728**

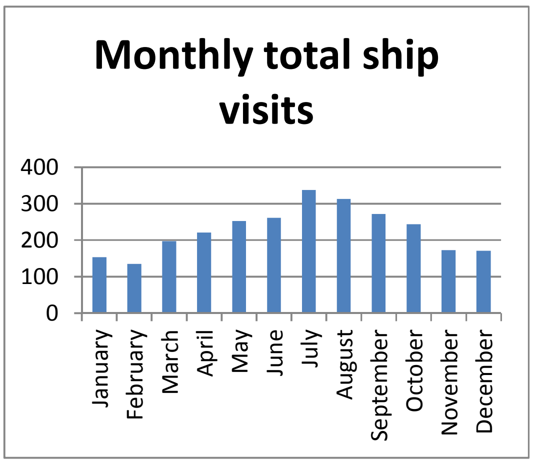


Figure 4.1; ship visits per month during 2010. Figures are totals of both ports.

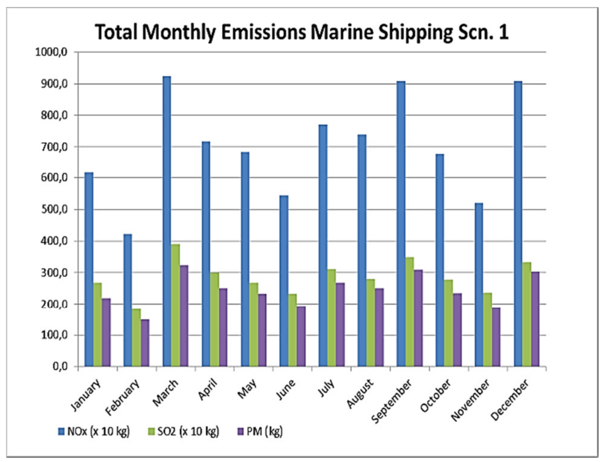


Figure 4.2; total monthly emissions from vessels visiting Groningen Seaports in 2010.

This indicates that one or more individual ship types are dominant in the emission trend. The dominant ship types are connected to shore power in scenario 2. To select ship type(s) for scenario 2, the emission per month per ship type ($\dot{E}$, formula below) is determined (table 4.3). This approach includes hoteling time, because the hoteling time of a vessel is a major determinant of the emissions.

$$\dot{E} = [e_{h(ms)} / T_{mean(ms)}] / N_{(ms)}$$

of which,

$e_{h(ms)}$ = monthly hoteling emission per ship type

$T_{mean\ (ms)}$ = monthly mean hoteling time per ship type

N_{ms} = amount of ship visits per month per ship type

In 2010 in Delfzijl and Eemshaven port the bulk carrier dominates the emissions. Bulk carriers have the second highest annual mean value for $\dot{E}$. Reefers are theoretically the most influencing type of ship, but there were only few ship visits by reefers in 2010, therefore this ship type is less relevant in this case. Bulk carriers are included in scenario 2, as well as tankers, because fuel use by tankers is high as compared to other ship types (table 4.4). Scenario 2a deals with bulk carriers supplied with shore power and scenario 2b deals with tankers supplied with shore power.

The values for container and RoRo vessels are neglected, because there were only three container ships visiting the ports. Many of the RoRo visits were done by the ferry to Borkum which is already connected to shore power when staying overnight.

Table 4.3; mean monthly NO_X emissions per hour hoteling time in kilograms per ship type per ship.

	Tanker	Bulk carrier	Container	General cargo	RoRo etc.	Reefer	Other
January	0.153	0.178	0	0.006	0.051	0.791	0.017
February	0.210	0.136	0	0.009	1.605	0.437	0.012
March	0.121	0.396	1.257	0.744	0.011	0.469	0.042
April	0.171	0.154	0	0.006	0.011	0.658	0.017
May	0.102	0.609	0	0.009	0.007	0.325	0.008
June	0.165	0.241	0	0.008	0.006	0.515	0.008
July	0.106	0.158	0	0.011	0.002	0.320	0.008
August	0.166	0.233	0	0.007	0.003	0.846	0.012
September	0.186	0.328	0.851	0.013	0.004	0.542	0.010
October	0.261	0.254	0	0.010	0.005	0.555	0.009
November	0.149	0.279	0	0.007	0.058	0.728	0.005
December	0.169	0.144	0	0.012	0.083	0.508	0.022
Annual mean *E*	**0.163**	**0.259**	**0.176**	**0.070**	**0.154**	**0.558**	**0.014**

4.1.2 Concentrations and depositions baseline scenario

Results from scenario 1 in OPS are presented in figures 4.3 and 4.4.

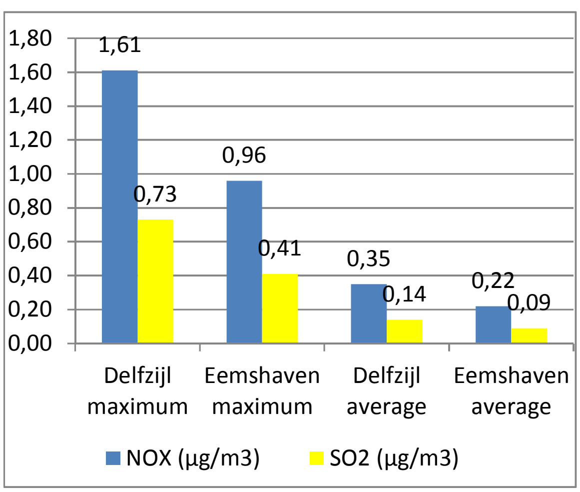


Figure 4.3; annual maximum and annual average concentration Values in 5x5 km area in baseline scenario in Delfzijl and Eemshaven port.

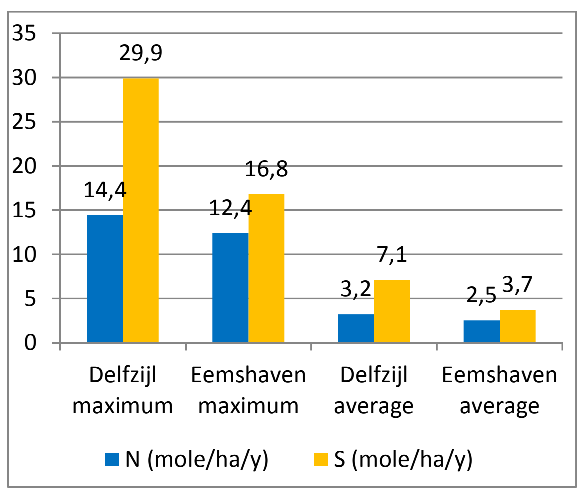


Table 4.4; annual maximum and annual average deposition values in 5x5 km area in baseline scenario in Delfzijl and Eemshaven port.

4.2 Results scenario 2; shore power

4.2.1 Bulk carriers with shore power

Scenario 2a deals with the shipping situation in 2010 and bulk carriers hypothetically connected to the ports power grid. In this scenario the total calculated annual NO_X emissions are 120.2 mt. For SO_2 and PM the total calculated annual emissions are respectively 49.5 mt and 4.2 mt. These results are differentiated for Delfzijl and Eemshaven port (table 4.4). The annual relative reduction in Delfzijl for NO_X is 4%, for SO_2 3.8%, and for PM 3.8%. In Eemshaven port the annual relative emission reduction for NO_X is 3.2%, for SO_2 3.7%, and for PM 3.3%.

4.2.2 Tankers with shore power

Scenario 2b deals with the shipping situation in 2010 and tankers hypothetically connected to the ports power grid (on shore power supply). In this scenario the total annual calculated NO_X emissions are 113.4 mt. For SO_2 and PM the total calculated emissions are respectively 44.8 mt and 3.9 mt. These results are differentiated for Delfzijl and Eemshaven port (table 4.4). The relative reduction in Delfzijl of NO_X is 18.4%, SO_2 23.9%, and PM 20%. In Eemshaven port the relative emission reduction of NO_X is 0.2%, SO_2 0.3%, and PM 0.2%. Only small sized tankers have visited Eemshaven port in 2010 in a limited number.

Table 4.4; annual emissions of shipping in Delfzijl and Eemshaven port when bulk carriers and tankers are supplied with shore power.

	Delfzijl Bulk carriers	Eemshaven Bulk carriers	Delfzijl Tankers	Eemshaven Tankers
NO_X emissions (kg)	58 047	62 173	49 322	64 092
- ***Marine***	*27 921*	*52 327*	*19 169*	*54 245*
- ***Inland***	*30153*	*9847*	*30 153*	*9847*
SO_2 emissions (kg)	26 336	23 147	20 847	23 967
- ***Marine***	*13 521*	*18 962*	*8032*	*19 782*
- ***Inland***	*12 815*	*4185*	*12 815*	*4185*
PM emissions (kg)	2141	2093	1780	2160
- ***Marine***	*1048*	*1736*	*687*	*1803*
- ***Inland***	*1093*	*357*	*1093*	*357*
Ship visits				
- ***Marine***	*764*	*1966*	*764*	*1966*
- ***Inland***	*2955*	*965*	*2955*	*965*
Total marine GT	$2.2 \cdot 10^6$	$4.8 \cdot 10^6$	$2.2 \cdot 10^6$	$4.8 \cdot 10^6$
Total marine hoteling time (hr)	$25.8 \cdot 10^3$	$57.8 \cdot 10^3$	$23.7 \cdot 10^3$	$58.5 \cdot 10^3$

4.2.3 Concentrations and depositions when bulk carriers supplied with shore power

OPS results from scenario 2a when bulk carriers are supplied with shore power are presented in figure 4.5 and 4.6.

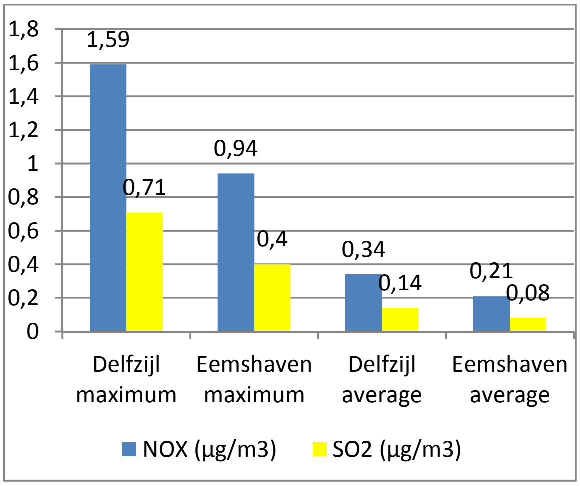


Figure 4.5; annual maximum and annual average concentrations in 5x5 km area concentration values when bulk carriers supplied with shore power in Delfzijl and Eemshaven port.

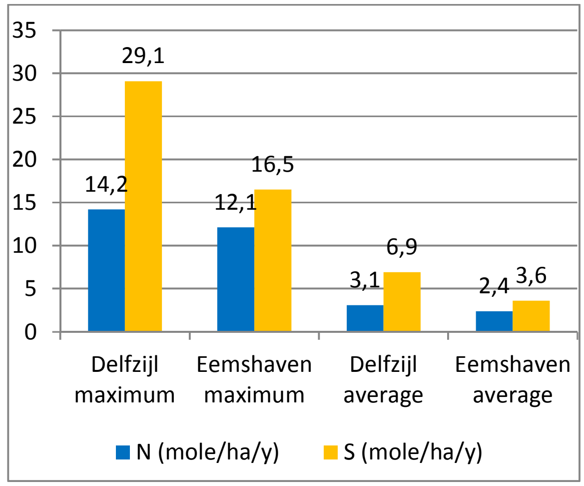


Figure 4.6; annual highest and annual average deposition in 5x5 km area deposition values when bulk carriers supplied with shore power in Delfzijl and Eemshaven port.

4.2.4 Concentrations and depositions when tankers supplied with shore power

Results from scenario 2b when tankers are supplied with shore power are presented in figures 4.7 and 4.8.

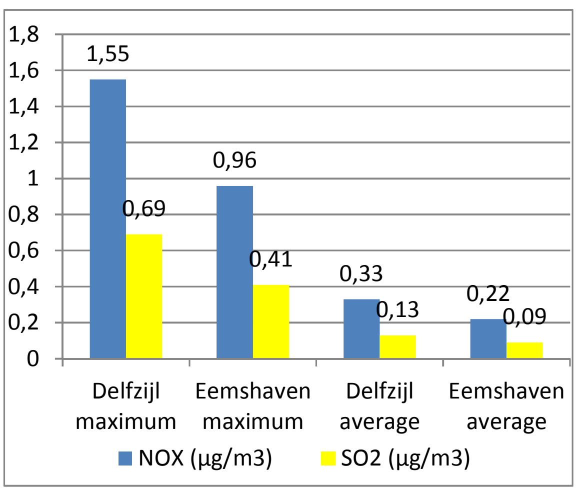


Figure 4.7; annual maximum and annual average concentrations in 5x5 km area concentration values when tankers supplied with shore power in Delfzijl and Eemshaven port.

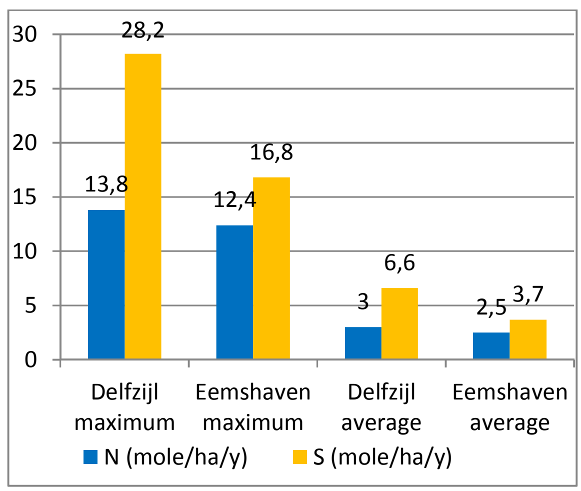


Figure 4.8; annual highest and annual average deposition in 5x5 km area deposition values when tankers supplied with shore power in Delfzijl and Eemshaven port.

4.3 Results scenario 3; energy port

Scenario 3 deals with an increase in ocean going vessel visits in Eemshaven port. This are 212 tankers and bulk carriers sized between 20 000 – 40 000 GT. Also 700 extra inland vessels are expected to arrive when the new power plants and oil terminal become operational. The increase in NO_X, SO_2, and PM emissions with respect to situation 2010 is respectively 59.1 mt, 30.7 mt, and 2.4 mt (table 4.5). In Eemshaven port the relative emission increase of NO_X is 92%, SO_2 127%, and PM 106%. There is no emission increase in Delfzijl.

Table 4.5; annual emissions of shipping in Eemshaven port in energy scenario.

	Eemshaven
NO_X emissions (kg)	123 604
- ***Marine***	*106 614*
- ***Inland***	*16 990*
SO_2 emissions (kg)	54 691
- ***Marine***	*47 470*
- ***Inland***	*7221*
PM emissions (kg)	4468
- ***Marine***	*3852*
- ***Inland***	*616*
Ship visits	
- ***Marine***	*2178*
- ***Inland***	*1665*
Total marine GT	$9.2 \cdot 10^6$
Total marine hoteling time (hr)	$70.9 \cdot 10^3$

4.3.1 Concentrations and depositions in energy scenario

Results from this scenario are presented in figures 4.9 and 4.10.

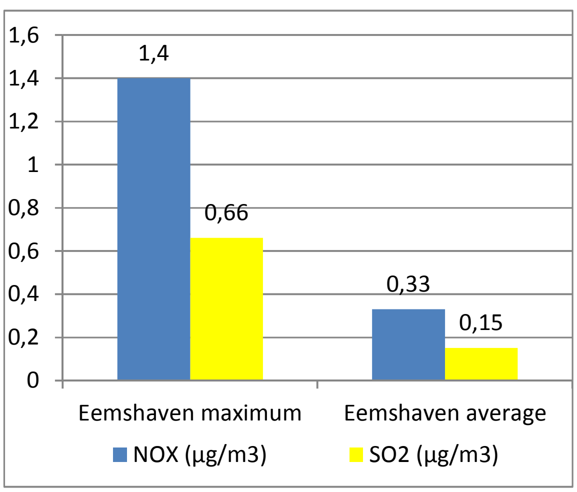


Figure 4.9; annual maximum and annual average concentration values in 5x5 km area in Eemshaven port in energy scenario.

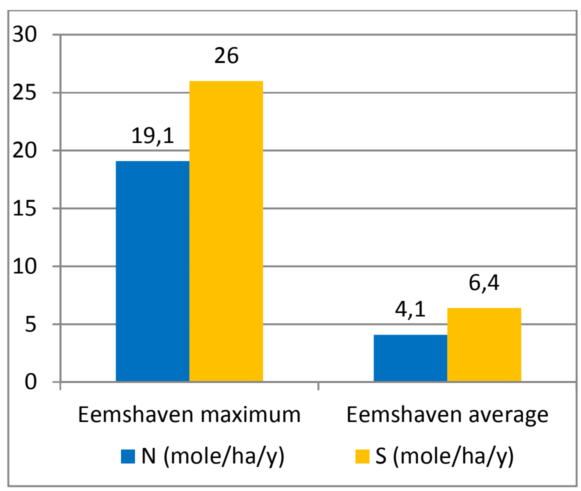


Figure 4.10; annual maximum and annual average deposition values in 5x5 km area in Eemshaven port in energy scenario.

4.3.2 Smaller ships in energy scenario

The total volume of the extra tankers which are estimated to visit the Eemshaven port is 880 000 GT. The total volume of the extra bulk vessels is 3 500 000 GT. When ships with lower cargo capacity due to draft limits will deliver the required cargo, more ships will visit the port (table 4.6). More ship visits result in higher sailing emissions in the port as well outside the port area when approaching and leaving. Cumulatively, the smaller vessels have a longer hoteling time, resulting in more hoteling emissions.

Table 4.6; annual visit frequency, hoteling time, and sailing emissions from handysize and panamax vessels compared to emissions from smaller vessels with the same total volume. The sailing emissions are the calculated emissions within the port. The hoteling time is estimated according $0{,}48 \cdot GT^{0{,}5}$ for tankers and $0{,}17 \cdot GT^{0{,}6}$ for bulkers.

	Original planned ships		Substitute ships	
	Tanker	**Bulk**	**Tanker**	**Bulk**
Ship visits (per year)	37	175	126	432
Hoteling time (hour)	1806	10438	3647	15117
Total sailing emission				
- **NO_X (kg)**		6956		8226
- **SO_2 (kg)**		4190		4993
- **PM (kg)**		362		452

4.4 Results scenario 4; offshore port

Scenario 4 deals with an annual increase of 50% of emissions from tugs and other offshore related traffic at Eemshaven port. The annual emission increase for NO_X, SO_2, and PM is respectively 17.8 mt, 3.5 mt, and 0.5 mt (table 4.7). The annual relative emission increase of NO_X is 25%, SO_2 19%, and PM 23%. There is no emission increase in Delfzijl.

Table 4.7; annual emissions of shipping in Eemshaven port in offshore scenario.

	Eemshaven
NO_X emissions (kg)	80 061
- ***Marine***	*70 214*
- ***Inland***	*9847*
SO_X emissions (kg)	28 576
- ***Marine***	*24 391*
- ***Inland***	*4185*
PM emissions (kg)	2656
- ***Marine***	*2299*
- ***Inland***	*357*

4.4.1 Concentrations and depositions offshore scenario

Results from this scenario are presented in figures 4.11 and 4.12.

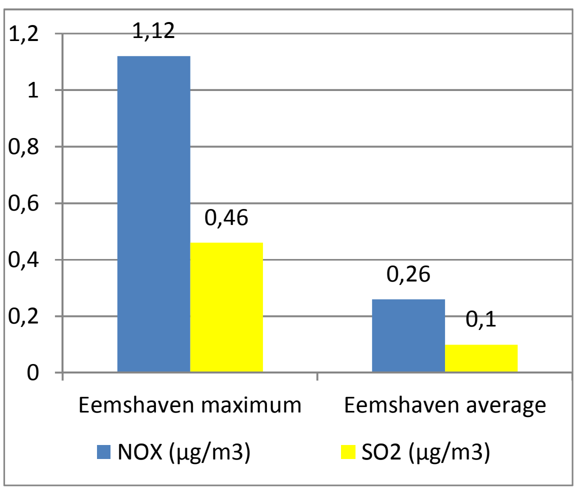


Figure 4.11; annual maximum and annual average concentration values in 5x5 km area in Eemshaven port in offshore scenario.

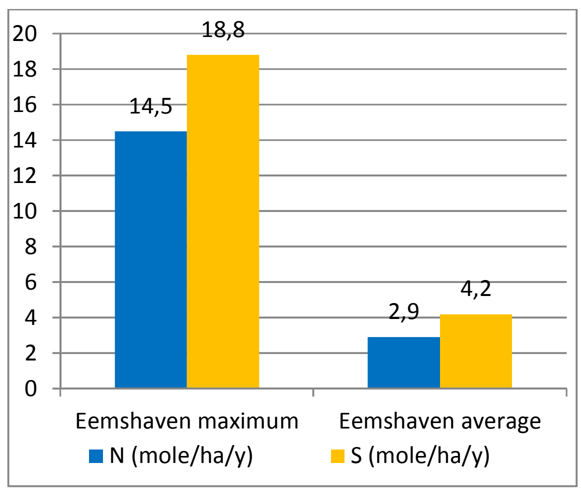


Figure 4.12; annual maximum and annual average deposition values in 5x5 km area in Eemshaven port in offshore scenario.

4.5 Results scenario 5; chemical port

Scenario 5 deals with a hypothetical growth of shipping in Delfzijl in the Oosterhorn area on the longer term. The increase in annual emissions is for NO_X, SO_2, and PM respectively 12.4 mt, 7.6 mt, 0.5 mt (table 4.8). The annual emission increase of NO_X is 21%, SO_2 28%, and PM 23%. There is no emission increase in Eemshaven port.

Table 4.8; annual emissions of shipping in Delfzijl in chemical scenario.

	Delfzijl
NO_X emissions (kg)	72837
- ***Marine***	*38666*
- ***Inland***	*34171*
SO_2 emissions (kg)	34987
- ***Marine***	*20464*
- ***Inland***	*14523*
PM emissions (kg)	2738
- ***Marine***	*1495*
- ***Inland***	*1243*
Ship visits	
- ***Marine***	*1164*
- ***Inland***	*3355*
Total marine GT	$3.15 \cdot 10^6$
Total marine hoteling time (hr)	$33.2 \cdot 10^3$

4.5.1 Concentrations and depositions chemical scenario

Results from this scenario presented in figures 5.13 and 5.14.

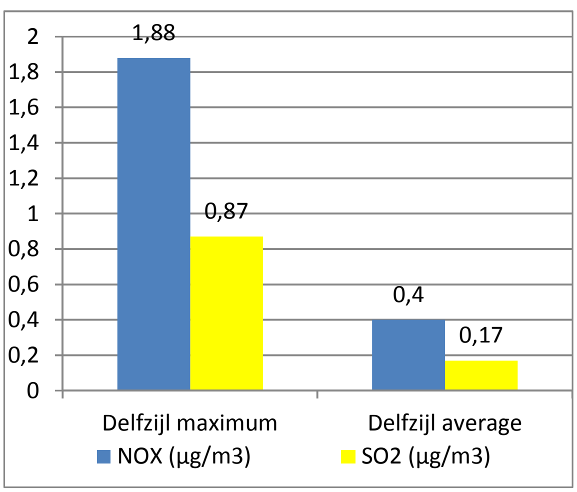


Figure 4.13; annual maximum and annual average concentration values in 5x5 km area in Delfzijl in chemical scenario.

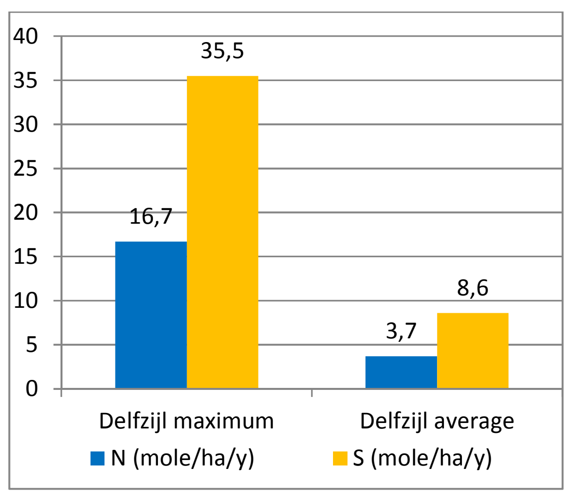


Figure 4.14; annual maximum and annual average deposition values in 5x5 km area in Delfzijl in chemical scenario.

Chapter 5: Evaluation

This chapter presents the evaluation of the results from Chapter 4 and relates the results to background concentrations and standards for concentration and deposition levels. The values of PM are insignificant when compared to the modelled background values and are left out of further analysis.

5.1 Emission distribution Groningen Seaports

5.1.1 Emissions versus concentration and deposition trends

The relative increase or decrease in emissions in the scenarios is higher than in maximum concentrations or depositions decrease (tables 5.1 and 5.2). This is most likely the effect of the specific dispersion of the emitted substances and the annual approach by the model (annual average wind direction, average wind speed, and annual average precipitation). Emission data are more robust and therefore preferred in the evaluation of scenario trends. The concentration and deposition data are used for the evaluation of the background contribution and exposure limits.

Table 5.1; NO_X and SO_2 annual emission decrease in Delfzijl and the resulting maximum concentration and deposition decrease compared to baseline scenario in Delfzijl.

	2a Bulk carriers shore power	2b Tankers shore power	5 Chemical
NO_X emission	-3%	-18%	+20%
Maximum NO_X concentration	-2%	-4%	+16%
Maximum N deposition	-2%	-6%	+16%
SO_2 emission	-4%	-24%	+28%
Maximum SO_2 concentration	-3%	-4%	+19%
Maximum S deposition	-3%	-5%	+19%

Table 5.2; NO_X and SO_2 annual emission increase and the resulting concentration and deposition increase in the energy and offshore scenario. The low shore power scenario results for Eemshaven ports are kept out of this table.

	3 Energy port	4 Offshore port
NO_X emission	+97%	+25%
Maximum NO_X concentration	+45%	+16%
Maximum N deposition	+54%	+17%
SO_2 emission	+127%	+19%
Maximum SO_2 concentration	+60%	+12%
Maximum S deposition	+54%	+12%

5.1.2 Spatial distribution

The exposure to the air pollutants in the scenarios is highest in the immediate surroundings of the emission positions (within the 5 km x 5 km area). Further away the contribution of shipping declines rapidly. In both ports the higher values are found in NE and SW direction (Annex 3). In the energy scenario the pollutants are distributed over a greater area, as result from the higher exhaust gas heat content emitted by the bigger vessels.

5.2 Scenario evaluation

5.2.1 Shore power supply

With bulk carriers connected to shore power, emission reduction is less than when tankers are connected to shore power (table 5.1). Less bulk carriers than tankers have visited the ports in 2010, 74 and 164 respectively. The mean reduction concerning tankers in Delfzijl is 5%. In Eemshaven port there is hardly any reduction as a result of limited tanker visits. For bulk carriers the emission reduction in both ports is 2%. From an air quality improvement perspective, in the Eemshaven it would be more effective to have bulk carriers supplied with shore power.

5.2.2 General cargo connected to shore power

When considering shore power supply to another frequent visitor in the ports, *e.g.* general cargo ships visiting the Delfzijl Handelskade (figure 5.1), the emission reduction level is between the levels of both scenarios above (table 5.3).

Figure 5.1; locations of Handelskade berths in Delfzijl.

The combination of ships visit frequency and berthing place makes it interesting to compare this case with the situations with bulk carriers and tankers supplied with shore power. The air pollution reduction relative to the baseline scenario would be between 2% and 5%.

Table 5.3; emission reductions in cases when specific general cargo vessels, tankers, or bulk carriers are supplied with shore power in Delfzijl.

	General cargo Handelskade	Tankers Delfzijl	Bulk carriers Delfzijl
Number supplied vessels	159	160	62
NO_X emission reduction (mt)	6.2	11.2	2.4
SO_2 emission reduction (mt)	2.4	6.6	1.1

In 2010 159 ships were visiting the Handelskade berths, which is 23% of total general cargo ship visits to Delfzijl. From a ship visit frequency perspective, it is more effective to connect tankers to shore power. In addition, the amount of space at the tanker jetties (5 jetties with connections for one vessel) is less than the berthing space (850 meters) of the Handelskade, making tankers preferred to be connected to the grid above general cargo ships, with regards to emission reduction profits, installation efforts, and investments.

5.2.3 Energy and offshore scenario

Both the energy (scenario 3) and offshore (scenario 4) scenario show significant annual emission increases and concentration and deposition increases in Eemshaven port.

Both the energy and offshore scenario are likely to take place in the near future. Thus emissions in both scenarios can be added to each other, resulting in a total emission increase in the future Eemshaven port. When these vessels are supplied with shore power, a large share of the extra emission is potentially prevented (table 5.4; figure 5.2). The effects of connecting the vessels in the energy and offshore scenarios to shore power are not calculated by OPS, as the emission situation then is identical to the base scenario.

Table 5.4; the increase of NO_X annual emissions and reduction potential by shore power in energy and offshore scenarios and combination. The shore power supply only applies to the extra visiting vessels in the scenarios. The table is restricted to NO_X. SO_2 emissions show a similar trend.

	Base scenario	Energy port	Offshore port	Energy + offshore
total NO_X emission (mt)	64.2	123.6	80.1	139.7
Emission increase (mt)	0	59.4	15.9	75.5
Emission increase (relative to base scenario)	0%	97%	25%	118%
Reduced emissions by shore power supply (mt)	0	73.6	67.3	76.9
Emission decrease (mt)	0	50	12.8	62.8
Reduction potential (relative to total emissions)	0%	40%	16%	45%

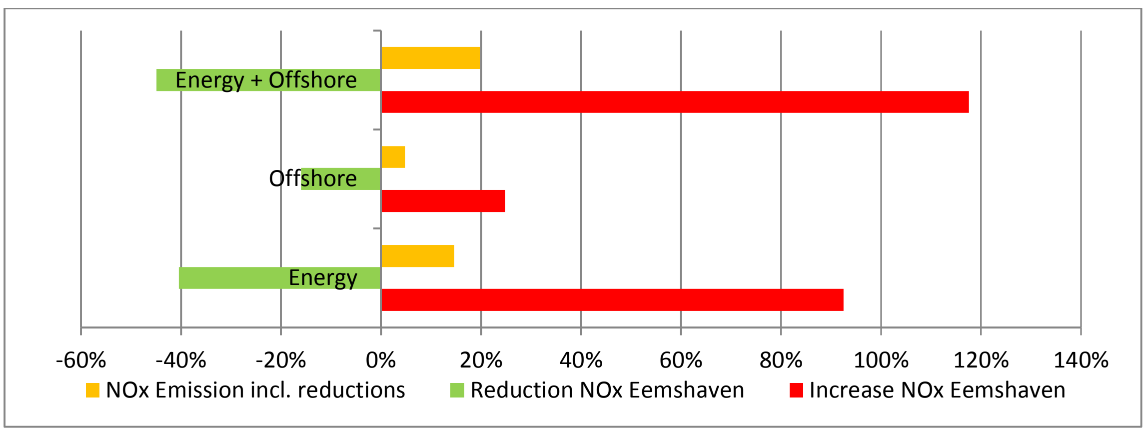


Figure 5.2; visualisation of table 6.4. The red bar represents the NO_X emission increase with respect to the base scenario. The orange bar represents the net result when the extra ships in the scenarios are supplied with shore power. The green bar represents NO_X emission reduction of the total annual NO_X emissions when extra ships are supplied with shore power.

The extra offshore vessels supplied with shore power have the highest relative emission reductions. In absolute terms emission reduction will be larger when the extra vessels in the energy scenario are supplied with shore power. However, there are limitations to the implementation of shore power to large vessels, as a result of high power demands by these vessels. High power demands might pose a difficulty in the implementation of shore power, as a result of technical limitations in handling and transferring large powers (see section discussion 8.2). The implementation of shore power to offshore vessels might be easier, because most of the vessels in this category are tugs. When in port, tugs are mostly waiting, having low power demands. These vessels have a comparatively long total hoteling time (with a total of 46 000 hours per year far more than the other ship categories; some individual ships have hoteling times over 100 hours per year). Many of these vessels are berthed on a limited selection of berths. This will result in lower investment requirements in the installation of the shore power connections.

5.2.4 Increased shipping Delfzijl

Scenario 5 deals with an increase in shipping in Delfzijl. The increase of the emissions by the extra ship visits causes an increase in concentration and deposition in the surroundings of the port by 16% - 20%.

The assumptions regarding the extra ship visits are based on a survey of the potential development of the Oosterhorn area within the Delfzijl port area. Whether these ships eventually will visit the port is uncertain, but this scenario indicates how the local air quality can be affected by increased shipping.

5.2.5 Difference emissions Eemshaven port and Delfzijl

The concentrations and depositions in the baseline scenario in Eemshaven port are lower than in Delfzijl, despite the nearly equal emission values in both ports. This is a result of differences in exhaust gas heat contents of the different ship types and the funnel heights of the vessels; more inland vessels with a funnel height of 6 meters are visiting Delfzijl emitting gasses with lower heat content.

Fewer ships have visited Eemshaven port in 2010 compared to Delfzijl, but in general the ships in Eemshaven port were bigger and had longer hoteling times. The high values for sulphur in Delfzijl are partly caused by inland shipping.

5.3 Evaluation to background concentrations

To evaluate the results of the OPS modelling local background concentration and deposition values for the area are required, as well as EU limit values for environment and health protection.

5.3.1 Background concentration

Modelled background concentrations and depositions in the Netherlands are presented by RIVM in concentration and deposition charts (table 5.5; Velders *et al*., 2011).

NO_X, SO_2, and PM concentrations are monitored at the German Waddensea island of Nordeney (Niedersächsisches Ministerium für Umwelt, 2012) and in the Dutch Kollumerwaard (RIVM, 2012), which are the nearest air pollution monitoring stations (table 5.5). In the summer of 2012 an average NO_X background concentration of 5 µg m^{-3} was monitored. Peaks of 17 µg m^{-3} are measured at both stations. NO_X concentrations at the Nordeney station depend on the wind direction (Annex 4). Higher (3 to 5 times) values are measured with winds from SW to SE directions. Probably land-based activities dominate the influence on the concentrations.

Table 5.5; Modelled and measured average (background) concentration values for NO_X, SO_2, and PM at Nordeney (n=75; 4-hourly values between 30 August and 11 September) and at Kollumerwaard (n=38; 4-hourly values between 5 September and 11 September); values in µg m^{-3}.

	Modelled	Measured at Nordeney	Measured at Kollumerwaard
NO_x	13.7	5	6
SO_2	0.9	2	2
PM	21.7	15	18

The monitoring values are based on analysis and representative for the Northern Netherlands, so these values are used as background concentration for the evaluation. Monitored values reflect real conditions more than modelled values. However, a limited amount of data was used to calculate the average concentrations. Though, the data are from a summer period, when the average concentrations are usually higher than annual average values (Matthias *et al*., 2010).

5.3.2 Background deposition

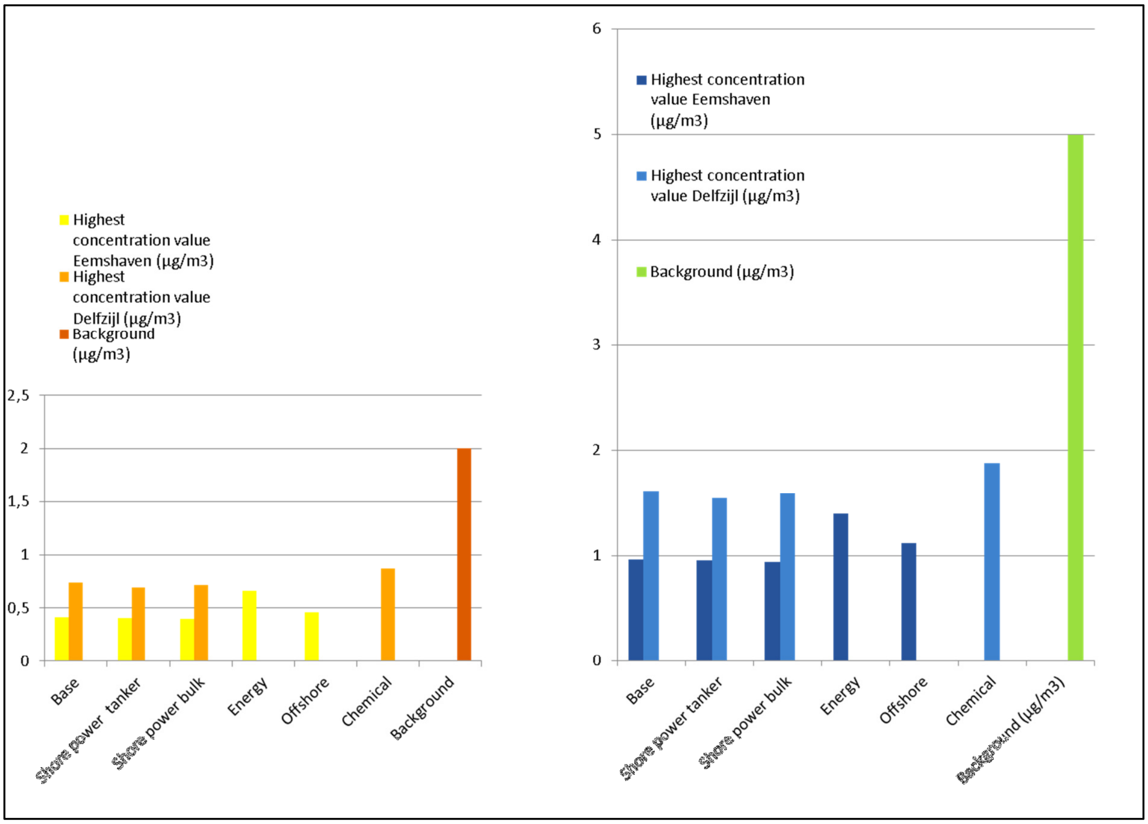
Modelled background deposition is also presented in the RIVM charts (table 5.6; Velders *et al*., 2011). Modelled deposition values are used as background deposition in this study due to the absence of deposition monitoring. The stations at Nordeney and Kollumerwaard do not determine nitrogen and sulphur deposition in the area.

Table 5.6; modelled deposition values for the northern Netherlands.

	Annual average deposition (mole ha^{-1} y^{-1})
Nitrogen	1435
Sulphur	300

5.3.3 Evaluation of scenarios to background concentration

The OPS maximum concentration values in all scenarios are a significant share (roughly 20-40%) of the measured background concentration values for NO_X as well as SO_2 (figures 5.3 and 5.4; table 5.7). On the contrary, the share of shipping in the background deposition is limited.



Figures 5.3 and 5.4; OPS maximum SO_2 (yellow) and NO_X (blue) concentration values compared to monitored background concentration values. Figure 6.3 (left) shows S concentrations; figure 6.4 (right) shows N concentrations.

Table 5.7; OPS maximum deposition values compared to RIVM modelled background deposition values.

	Background	Base scenario Delfzijl
Deposition (mole ha^{-1} y^{-1})		
N	1435	14.4
S	300	29.9

5.4 Evaluation of scenario to EU air pollution standards

5.4.1 Concentration limits

The European Parliament agreed on directives concerning standards for maximum concentration and deposition levels (EU, 2001; EU, 2008). When these levels are being reached, the responsible member state should undertake action to reduce the emission of the specific substance.

Relevant standards regarding to this study are the nature critical levels and the health limit values, both based on scientific evidence. The critical levels refer to the effects of acidification to vegetation and nature (table 5.8). The limit values refer to the effects of substances and photochemical smog to the human pulmonary system. Critical values are presented as annual averages, limit levels also focus on short-term exposure.

Table 5.8; concentration limits set by the European Union in order to protect health and nature (EU, 2008).

Average period	Critical levels
Sulphur dioxide	
Calendar year	20 µg m^{-3}
Nitrogen oxides	
Calendar year	30 µg m^{-3}
Average period	**Limit levels**
Sulphur dioxides	
One hour	350 µg m^{-3}
One day	125 µg m^{-3}
Nitrogen oxides	
One hour	200 µg m^{-3}
Calendar year	40 µg m^{-3}
PM	
One day	50 µg m^{-3}
Calendar year	40 µg m^{-3}

In all scenarios the OPS concentrations in Delfzijl and Eemshaven port are far below the concentration limits for nature as well as health. Even in bigger ports like Rotterdam the monitored concentrations are within the health limits in 2009 (DCMR, 2009). The critical values are not exceeded as well in Rotterdam on an annual average basis; however, temporal exceeding occurs.

5.4.2 Deposition limits

Critical values for N and S deposition vary with the specific ecology of the exposed area (APIS, 2012a). However, these limits are not legal limits; the EU only applied limits regarding the concentration. These values are based on scientific studies.

The Waddensea area adjacent to the ports is a saltmarsh (figure 5.5; Bakker, *et al*., 2005). Saltmarshes are *inter alia* tidal mudflats acting as interface between land and sea and have specific critical deposition levels (table 5.9).

Table 5.9; critical nitrogen deposition values for saltmarshes versus modelled nitrogen deposition in the Northern Netherlands (APIS, 2012b).

	Deposition (mole ha^{-1} y^{-1})
Critical	1430 – 2140
Modelled background	1435

The modelled values in the northern Netherlands for N have reached the critical deposition range for saltmarshes. Although the contribution of shipping in Delfzijl and Eemshaven ports is rather small, more ship emissions would contribute to an extra N deposition to the saltmarsh adjacent the ports.

Figure 5.5; intertidal mudflat in Waddensea. The Waddensea area near Eemshaven port is similar.

5.4.3 Borkum

At present there is a discussion about the effects of ship emissions in Eemshaven on the neighbouring German island of Borkum (Koolstra *et al.*, 2012). The German Wadden island of Borkum has a special interest in clean air as a tourist attraction and is situated approximately 15 km north of Eemshaven port. Therefore an OPS run for Borkum was performed. The influence of the air pollution by shipping in the ports is insignificant (table 5.10).

Table 5.10; contribution of shipping in the ports to concentration and deposition of nitrogen and sulphur substances on the German island of Borkum.

Total annual average …	Base scenario	Energy scenario
NO_X concentration	$9.5 \cdot 10^{-3}$ µg m^{-3}	$11 \cdot 10^{-3}$ µg m^{-3}
N deposition	$85 \cdot 10^{-3}$ mole ha^{-1} y^{-1}	$130 \cdot 10^{-3}$ mole ha^{-1} y^{-1}
SO_2 concentration	$2.2 \cdot 10^{-3}$ µg m^{-3}	$3.2 \cdot 10^{-3}$ µg m^{-3}
S deposition	$60 \cdot 10^{-3}$ mole ha^{-1} y^{-1}	$109 \cdot 10^{-3}$ mole ha^{-1} y^{-1}

Chapter 6: Conclusions

The aims of this study are:

1. to quantify ship emissions and their contribution to local atmospheric air pollution in the Eemshaven-Delfzijl area,
2. to evaluate the relevance of shipping as a source of pollution,
3. to evaluate whether emission shore power as an emission reduction measure is effective in medium size ports like Eemshaven port and Delfzijl.

Conclusions aim 1

Emissions by shipping in Groningen Seaports are calculated by the methodology of the EMS protocol. The order of annual emission is 125 mt for NO_X and 52 mt for SO_2. PM levels emitted by shipping in Groningen Seaports are very low. Groningen Seaports are the sixth commercial shipping ports in the Netherlands leading to a relatively low emission as compared to total annual Dutch ship emissions in ports. However, energy and offshore activities in Eemshaven port are expanding.

With the expected increase in shipping in Eemshaven port, the annual emissions will roughly double when handysize and panamax ships will visit Eemshaven port to supply the power plants and oil terminal. When these vessels are replaced by smaller vessels, as result of the relative shallow fairway to Eemshaven port, emissions will increase even more. Offshore shipping is another expanding activity in Eemshaven port, contributing to increasing emission levels.

Annual average NO_X and SO_2 concentration and deposition values as a result of shipping in the port area were modelled by OPS. In all scenarios values do not violate the maximum concentration and deposition levels set by the European Union.

Conclusions aim 2

The maximum concentrations as a result of shipping are a significant share of the background concentrations in the area, indicating that the contribution of shipping is significant. Maximum concentrations are found adjacent to the emission sources within the 5 km x 5 km area. For Eemshaven port the Waddensea is the direct adjacent area. The border of the Waddensea is a fragile salt marsh ecosystem and susceptible for air pollutants.

Conclusions aim 3

Hoteling is the main shipping activity in ports concerning emissions. Shore power is a potential measure to reduce hoteling emissions. The emission increase in Eemshaven port creates a potential for shore power, especially for offshore tugs, because the implementation for these vessel is quite easy. The potential for shore power in Delfzijl is highest for tankers supplied with shore power.
Implementation of emission reduction measures will contribute to improvement of the air quality in the extended port areas. The adjacent Waddensea area will benefit from ship emission reduction policies.

Chapter 7: Discussion

7.1 Concerning other emission sources

This study is limited to shipping within the port limits of the Groningen Seaports. Within the port limits the Groningen Seaports authority has direct responsibility concerning port activities and ship movements. However, shipping emissions are not restricted to the port areas. In the approaches of the ports the vessels will emit air pollutants as well. When more vessels visit the ports the wider Ems area will also suffer more air pollution.

Within the port areas shipping is not the only source of pollutants. To gain full understanding of the magnitude of atmospheric emissions in commercial ports, emissions from port based industries, road traffic, diesel trains, cranes, etc. need to be included (Aldrete *et al*., 2007). Significant industrial sources in the port areas of Groningen Seaport are power plants, metal industries, and chemical industries. For example, Aldel is an aluminium production plant in Delfzijl and is one of the largest emission sources of CO_2 and other air pollutants in the Netherlands (Visschedijk *et al*., 2007).

7.2 Concerning the emission inventory

The accuracy of the EMS emission modelling is limited by the use of average values for fuel use and main engine power share; emission factors are general assumptions. Actual installed machinery and fuel use may deviate; however, detailed investigation is very labour-intensive.

A major deficit in the methodology is the assumed linear relationship between ship volume and energy consumption. In fact bigger vessels are more energy-efficient, so the emissions for bigger vessels may be overestimated in this study as well as underestimated for smaller vessels. Non-linearity is achieved when using the installed power as functional unit for emission factors. The EMS protocol includes emission factor figures with this functional unit, but for many vessels the installed power is not recorded. Gross tonnage data is widely available and is suitable to be used (Hulskotte & Denier van der Gon, 2010). However, for real time emissions a non-linear relationship between GT and fuel use needs to be investigated and implemented.

Another limit to the accuracy is raised by the limits to model the inland vessel emissions. The exact behaviour of inland shipping is not known. Dutch emissions calculations only include emissions from sailing inland vessels (Jimmink *et al*., 2012). This study includes hoteling emissions from inland shipping. Therefore, inland shipping emissions are based on coarse assumptions regarding the energy use by this shipping category.

The actual S-content in the fuel of the vessels in this study is unknown. Compliance with the less than 1.5% S-content legislation as well as the NO_X regulations is assumed. The fuel consumption for the category Other Ships (*i.e.* tugs) is based on the fuel use of a low amount of ships (n=3), but at the present the most adequate value (Hulskotte & Denier van der Gon, 2010). The Other Ships category not only applies for offshore shipping and tugs, but also to dredgers and ships that do not fit within the other categories.

In the scenario ships are virtually supplied with shore power, the heat supply by the boilers is included in the substitution. However heat on board usually cannot be produced with electrical energy. Electricity cannot instantly supply the heat demand on board and most vessels are not designed for using electricity for heat production. Emission reductions as result of shore power supply are probably overestimated; however, data on heat demand is not separately available.

7.3 Concerning atmospheric modelling

Chemical analysis of pollutant concentrations and deposition is preferred over modelling pollutant concentrations and deposition only. Models are a great feature in research and a cost effective help in understanding systems, but models are limited and need monitor validation. For example, the monitored NO_X and SO_2 concentrations in the Waddensea area differ widely from the modelled values for the entire northern Netherlands.

In the Northern Netherlands only one monitoring station is in practice (Kollumerwaard). Compared to Germany monitoring stations in the Netherlands are very sparse, especially in the north. Local and regional increase in air pollution is not monitored. Sound data on air pollution in the ports areas are not available.

The output of OPS is limited to annual average concentration and deposition. Real-time peak pollution levels cannot be modelled nor evaluated to EU peak concentration limits. However, the emission pattern of shipping in ports may show major peaks as demonstrated by Lonati *et al.* (2010).

A probable peak situation occurs for example when the ferry to Borkum arrives at Eemshaven port on a windless summer day. The vessel arrives and starts to unload and to load its passengers and passenger cars. Probably the main engines are kept running, as the ferry will only be in port shortly to be able to make several trips to the island per day. Together with the emissions of main engines, emissions from the loaded cars will contribute to a high emission peak at the ferry landing place. The emission will hardly be dispersed, as there is no wind at inversed atmospheric conditions. The emissions will add up to the emissions from earlier that day, resulting in high pollutant concentrations.

7.4 Concerning shipping emissions policy

In the emission ceilings decreed by the European Union marine ship emissions are excluded. The ceilings are based on land-based emissions, including inland shipping. The ceiling values vary for the various member states (EU, 2001; table 7.1). Shipping as a worldwide transport modality is submitted to IMO legislation, applying to the vessel regardless its position.

Table 7.1; national emission ceilings for SO_2, and NO_X to be attained in 2010. Ocean going shipping is excluded in the levels.

Country	SO_2 (kilotonnes)	NO_X (kilotonnes)
Belgium	99	176
Denmark	55	127
Finland	110	170
France	375	810
Germany	520	1051
Greece	523	344
Ireland	42	65
Italy	475	990
Netherlands	50	260
Portugal	160	250
Spain	746	847
Sweden	67	148
UK	585	1167
Total Shipping Emission NL	40	106

Including hoteling emissions from marine vessels in the EU ceiling levels would stimulate port policies towards emission reduction, as the port states would be obliged to apply ship emission mitigation strategies, especially when ceiling levels are exceeded. When Dutch ship emissions are included, the ceilings will be exceeded (table 7.1). The incentive would also count for the gearing of local port initiatives, national/EU clean air policy and IMO implementation.

Chapter 8: Recommendations

8.1 Methodological recommendations

Three main issues concerning the methodologies used in this study need more attention:

1. Relationship between gross tonnage and emissions.
   The relationship between the gross tonnage and the emissions of a vessel is not linear. Gross tonnage information is widely available, so a methodology using gross tonnage is preferred over a methodology using the installed power of a vessel.
2. Inland vessel emissions calculation methodology.
   Inland shipping is an important ship category. At present only sailing inland vessels are included in emission calculations. This study showed that hoteling emissions have a great share in the total in-port emissions from vessels. Inland shipping is expected to have a large share in hoteling emissions too. The inland shipping emission calculation methodology by the EMS protocol uses a functional unit for the emission factor which is not widely available. To calculate emissions that are closer to reality a functional unit like the tonnage of an inland vessel is recommended. Data on the tonnage of an inland vessel that is widely available.
3. The implementation of air quality monitoring.
   Measuring data is more realistic than modelled data concerning atmospheric concentrations. Models for concentration calculations need validation from monitoring.

8.2 Implementation of shore power

Shore power, when implemented, will save energy costs for ship owners and will reduce engine noise in the ports. Shore power will become interesting for the shipping industry when the fuel prices keep rising. Shore power is an emission reduction option that is considered by Groningen Seaports. There is a significant reduction potential for emission reduction in the ports for using shore power. However, there are limitations to the implementation and use of shore power. It is recommended for the ports to be aware of these limitations.

In first instance, the port authority should be aware of the risk of shifting the air pollution problem. This would be the case when the shore power is produced by fossil fuel based power stations in Eemshaven port. Detailed investigation the effects of implementing reduction measures in other places are required. Renewable sources for shore power are recommended, for these sources are (almost) emission-free. Renewable sources fit within the policy of Groningen Seaports; existing connections are already supplied by renewable energy when available.

Secondly, ships have high power demands which impede the way the connection should be established (Boretti, 2012). The frequency of the currents used on board the world fleet is not uniform. Different types of plugs with different configurations are available as well. Uniformity is necessary, because it is impracticable for ports to facilitate different shore power systems with different frequencies and plug configurations. Several maritime classification societies developed procedures for save connecting ships to shore power (IMO, 2012).

Lastly, ports and shipping companies have to invest in technologies to make the berths and ships able to be connected. Ships, for instance, need to be installed with extra switch boards and connection sockets (figure 8.1). Costs to prepare vessels for shore power are estimated between €150 000,- and €300 000,- (ELECTROWATT-EKONO, 2006). Ports have to install the shore power infrastructure. Costs to install a full system in port per berth can be estimated around €1.5 million (personal reference). What needs to be installed are possible converters for different ship current frequencies, like cables, transformer buildings etc. (Ericsson & Fazlagic, 2008).

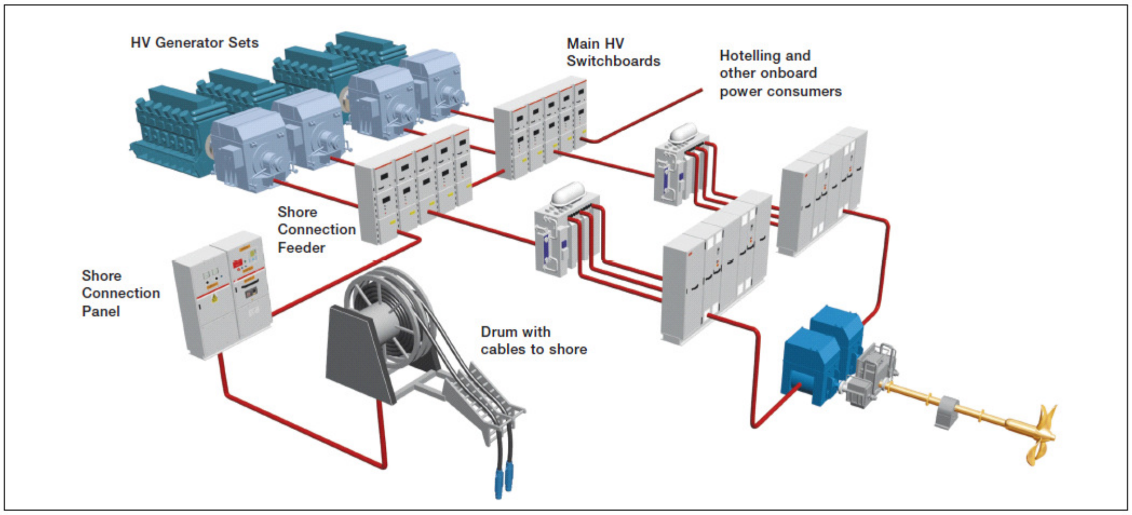


Figure 8.1; on-board power generation layout including shore power connection. Extra switch boards need to be installed (ABB, 2010).

In the ports there is already some experience with onshore power supply. The port authority already prepared newly built jetties and berths to be able to facilitate shore power. In Delfzijl and Eemshaven port the two floating jetties are supplied with shore power connections. Inland vessels and fishing vessel that are berthed to these jetties and which can be connected to shore power are obliged to connect to shore power (Groningen Seaports, 2011). Major users of shore power are the ferries to Borkum when the vessels pass the night in Eemshaven port.

This study did not focus on shore power for inland shipping, since the specific behaviour and emissions are unknown. Inland vessels have no high power demands and could be easier supplied with shore power. The funnel height of these ships is low producing very local air pollution. In the direct surroundings of these vessels the air pollution can be reduced significantly.

Annexes

Annex 1 Model results

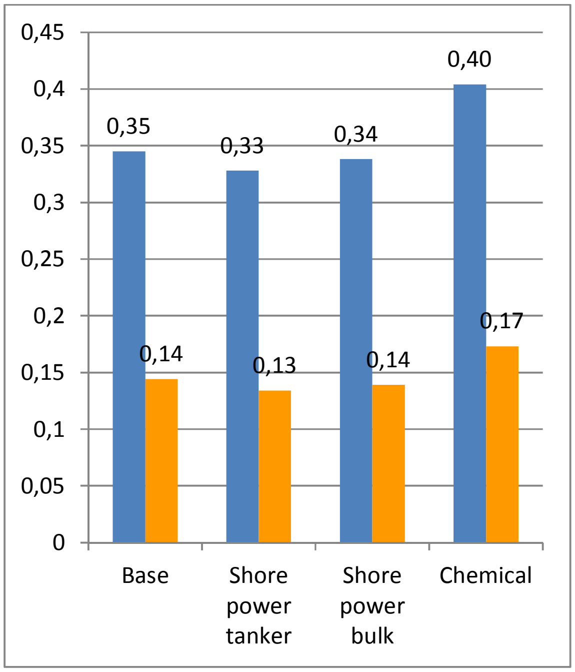


Figure 10.1; annual average concentrations in μg m^{-3} for NO_X (blue) NO_X and SO_2 (orange) in Delfzijl.

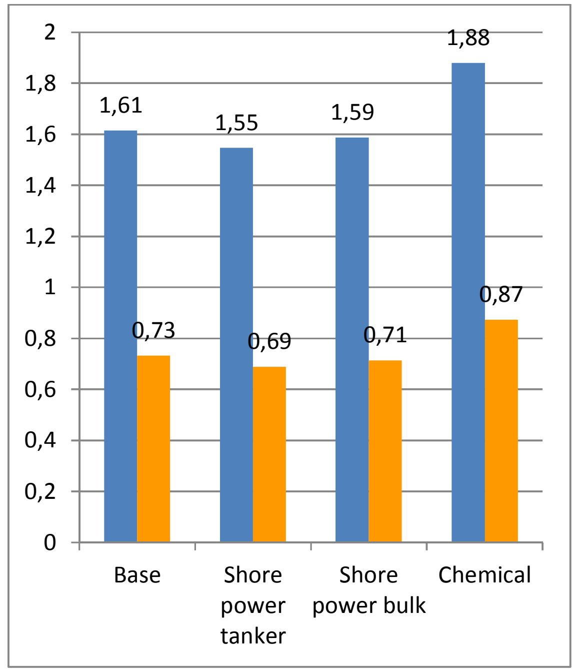


Figure 10.2; annual maximum concentrations in μg m^{-3} for (blue) and SO_2 (orange) in Delfzijl.

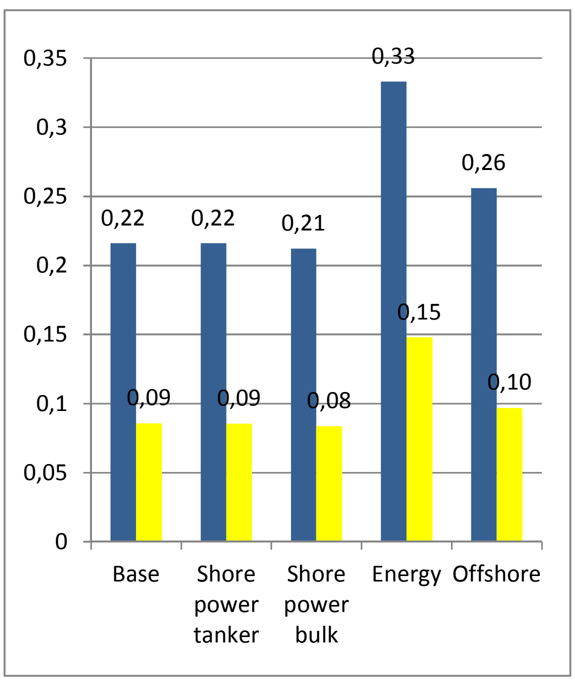


Figure 10.3; annual average concentrations in μg m^{-3} for NO_X (dark NO_X blue) and SO_2 (yellow) in Eemshaven port.

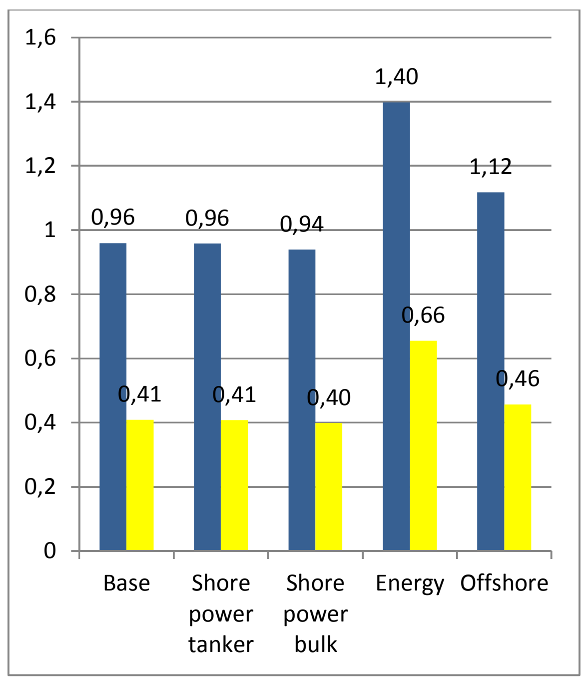


Figure 10.4; annual maximum concentrations in μg m^{-3} for (dark blue) and SO_2 (yellow) in Eemshaven port.

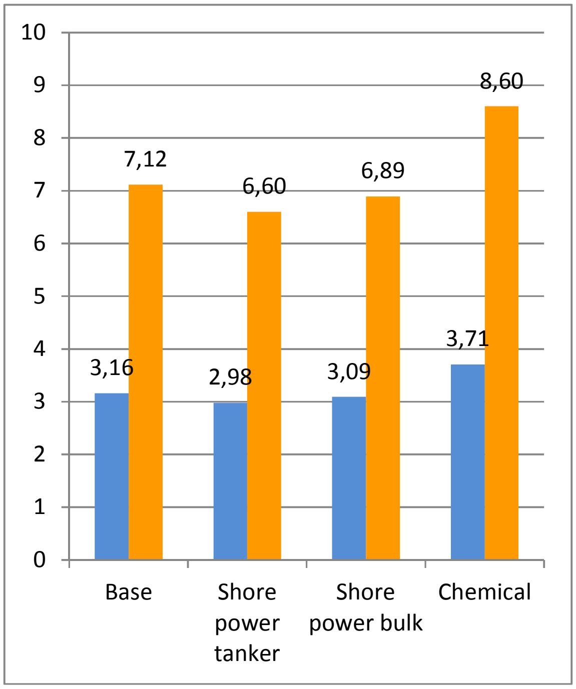


Figure 10.5; annual average deposition in mole ha^{-1} yr^{-1} for N (blue) N and S (orange) in Delfzijl.

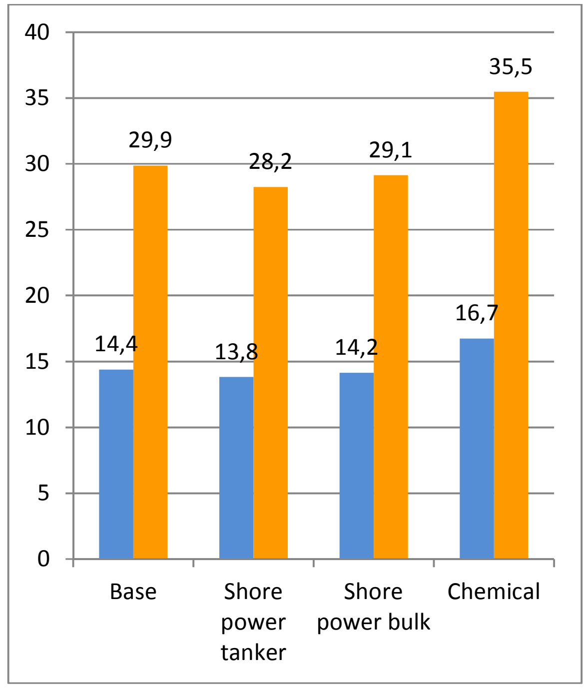


Figure 10.6; annual maximum deposition in mole ha^{-1} yr^{-1} for (blue) and S (orange) in Delfzijl

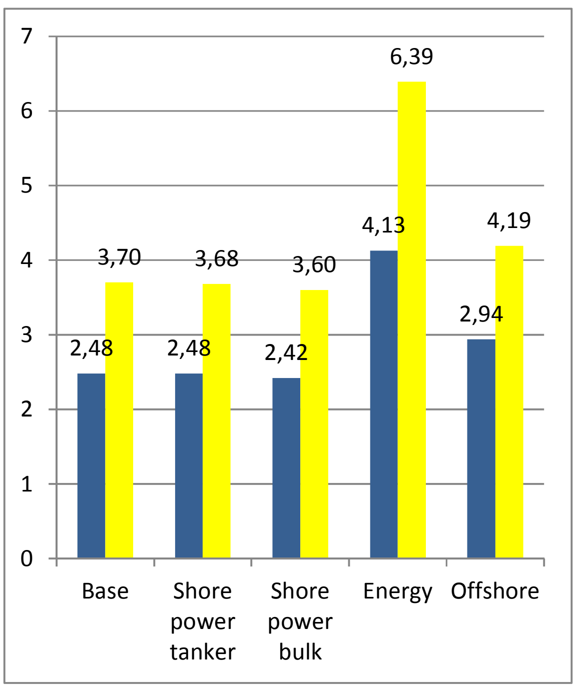


Figure 10.7; annual average deposition in mole ha^{-1} yr^{-1} for N (dark N blue) and S (yellow) in Eemshaven port.

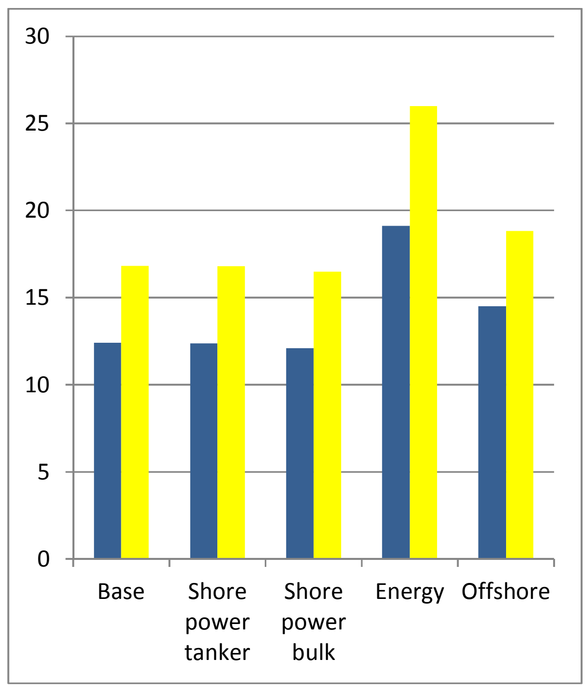


Figure 10.8; annual maximum deposition in mole ha^{-1} yr^{-1} for (dark blue) and S (yellow) in Eemshaven port.

Annex 2 Average highest presented concentration and deposition values

OPS does not present highest emission and deposition values of an emitted substance as an output value. The presented values depend on the positions of the grid cells. The presented values are the concentrations or deposition in the centre of a grid cell. Other concentration and deposition values are presented when the grid is shifted. In order to include the highest values, which may not have been presented in the output of the model, the average is taken from the highest presented concentration or deposition values and their eight adjacent values. When applying this approach possible grid shifts are not problematic, because the averages would not differ much. However, the average values are lower than the highest value calculated by the model.

```
Project  : Scenario1_allships_D_NOx
Substance: NOx
Date/time: 21-08-2012; 14:22:08
=========================== OPS-4.3.15  09 dec 2011 ===========================

concentration distribution of NOx: ( 1.E-02 ug/m3 NO2 )

 14  16  14  11  15  19  24  24  19  15

 16  19  24  27  21  30  37  27  21  17

 18  23  31  35  38  70  51  33  22  16

 20  27  38  65 184 344  75  35  22  16

 22  30  46  85 301 311  79  35  19  14

 22  25  43  56  72  49  30  32  25  12

 15  22  25  29  26  21  18  19  14  17

 14  16  18  21  16  13  15  11  10  12

 12  13  15  14  11  10  10   9  10   9

 11  12  12  12  10  10   9   9  12   7

grid cell dimension  :  0.500 km
number of grid points:  10x  10
top left coordinates :  256.257,  595.975 km

average NOx concentration                         : 0.345E+00 ug/m3
eff. chem. conv. rate                             :     2.831 %/h
```

Figure 10.9; visualization of taking the average of the highest presented NO_X concentration value and the eight adjacent concentration values in Delfzijl. This is an example of result presentation by OPS. The presented values in the grid are the concentrations in the centre of the grid cell. The grid is in RD coordinates.

Annex 3 Concentration distribution

```
Project  : Scenario1_allships_D_NOx
Substance: NOx
Date/time: 21-08-2012; 14:22:08
========================== OPS-4.3.15  09 dec 2011 ===========================

concentration distribution of NOx: ( 1.E-02 ug/m3 NO2 )

 14  16  14  11  15  19  24  24  19  15

 16  19  24  27  21  30  37  27  21  17

 18  23  31  35  38  70  51  33  22  16

 20  27  38  65 184 344  75  35  22  16

 22  30  46  85 301 311  79  35  19  14

 22  25  43  56  72  49  30  32  25  12

 15  22  25  29  26  21  18  19  14  17

 14  16  18  21  16  13  15  11  10  12

 12  13  15  14  11  10  10   9  10   9

 11  12  12  12  10  10   9   9  12   7

grid cell dimension  :  0.500 km
number of grid points:  10x  10
top left coordinates :  256.257,  595.975 km

average NOx concentration                        : 0.345E+00 ug/m3
eff. chem. conv. rate                            :     2.831 %/h
```

Figure 10.10; visualization of the spatial concentration distribution of the highest presented NO_X concentration values in Delfzijl. The intersection of the lines is the position of the emission source. The highest NO_X calculated concentrations are located around 750 meters north and north-east of the source position.

```
Project  : Scenario1_allships_E_NOx
Substance: NOx
Date/time: 21-08-2012; 16:00:05
========================== OPS-4.3.15  09 dec 2011 ============================

concentration distribution of NOx: ( 1.E-02 ug/m3 NO2 )

   4    5    5    7    8   10   13   14   13   12

   5    5    6    7   10   14   18   18   15   12

   6    7    8    9   14   22   27   22   17   13

   8    9   11   15   28   53   41   26   18   13

   9   11   13   29   91  207   63   29   17   13

  11   14   29   51  150  182   49   24   15   11

  11   17   22   32   45   37   25   16   12   10

  13   15   18   24   21   17   15   11    9    8

  11   13   15   15   13   11   10    9    8    7

  10   11   14   13   10    9    8    7    6    6

grid cell dimension  :  0.500 km
number of grid points:  10x  10
top left coordinates :  249.159,  610.407 km

average NOx concentration                         : 0.216E+00 ug/m3
eff. chem. conv. rate                             :     2.702 %/h
```

Figure 10.11; visualization of the spatial concentration distribution of the highest presented NO_X concentration values in Eemshaven port. The intersection of the lines is the position of the emission source. The highest calculated NO_X concentrations are located just surrounding the source position (within 750 meters range).

3	3	3	4	4	4	5	5	6	7	9	10	10	10	9	7	7	6	6	5
3	4	4	4	4	4	5	6	7	9	11	12	12	11	9	8	7	6	6	5
4	4	4	4	5	5	5	7	9	11	15	15	14	11	10	8	7	7	6	5
4	4	4	5	5	6	7	8	11	16	20	19	14	12	10	9	7	6	6	5
5	5	5	5	6	8	9	11	18	29	30	21	17	13	10	8	7	7	6	5
5	6	6	6	8	10	13	20	46	76	43	25	17	14	10	9	7	6	6	5
5	7	7	8	9	12	15	40	186	221	56	25	16	12	9	8	7	6	5	5
6	6	8	10	12	16	31	59	114	92	34	19	14	10	8	7	6	5	5	5
6	7	8	9	12	18	22	30	32	26	20	13	10	9	7	6	6	5	5	4
6	7	8	10	13	14	18	21	17	14	12	10	8	7	7	5	5	5	4	4
7	7	9	10	11	13	14	13	11	10	9	8	7	6	6	5	5	4	4	4
6	7	8	9	10	10	13	11	9	8	7	7	6	5	5	4	4	4	4	4
6	7	7	7	8	9	9	8	6	6	6	6	5	5	4	4	4	4	3	3
6	6	6	6	7	7	7	6	6	6	5	5	4	4	4	4	4	3	3	3

Figure 10.12; visualization of the spatial concentration distribution of the highest presented NO_X concentration values in Eemshaven port in wider spatial scale than figure 9.11. The distribution shows a distribution in north-eastern and south-western direction. This figure shows the difference in presented concentration values by a grid cell shift. The emission sources are located within the square.

Annex 4 MARPOL Annex VI, Regulation 13 and 14

Regulation 13; *Nitrogen oxides (NO_X)*

Application

1.1 This regulation shall apply to:

1.1.1 each marine diesel engine with a power output of more than 130 kW installed on a ship; and

1.1.2 each marine diesel engine with a power output of more than 130 kW that undergoes major conversion on or after 1 January 2000 except when demonstrated to the satisfaction of the Administration that such engine is an identical replacement to the engine that is replacing and is otherwise not covered under paragraph 1.1.1 of the regulation.

1.2 This regulation does not apply to:

1.2.1 a marine diesel engine intended to be used solely for emergencies, or solely to power any device or equipment intended to be used for solely emergencies on the ship on which it is installed, or a marine diesel engine installed on lifeboats intended to be used solely for emergencies; and

1.2.2 a marine diesel engine installed on a ship solely engaged in voyages within waters subject to the sovereignty or jurisdiction of the State flag of which the ship is entitled to fly, provided that such engine is subject to an alternative NO_X control measure established by the Administration.

1.3 Notwithstanding the provisions of paragraph 1.1 of this regulation, the Administration may provide an exclusion from the application of this regulation for any marine diesel engine that is installed on a ship constructed, or for any marine diesel engine that undergoes a major conversion, before 19 May 2005, provided that the ship on which the engine is installed is solely engaged in voyages to ports of offshore terminals within the State flag of which the ship is entitled to fly.

Major conversion

2.1 For the purpose of this regulation, *major conversion* means a modification on or after 1 January 2000 of a marine diesel engine that has not already been certified to the standards set forth in paragraph 3, 4, or 5.1.1 of this regulation where:

2.1.1 The engine is replaced by a marine diesel engine or an additional marine diesel engine is installed, or

2.1.2 any substantial modification, as defined in the revised NO_X Technical Code 2008, is made to the engine, or

2.1.3 the maximum continuous rating of the engine is increased more than 10% compared to the maximum continuous rating of the original certification of the engine.

2.2 For a major conversion involving the replacement of a marine diesel engine with a non-identical marine diesel engine or the installation of an additional marine diesel engine, the standards in this regulation in force at the time of the replacement or addition of engine shall apply. On or after 1 January 2016, in the case of replacement engines only, if it is not possible for such replacement engine to meet the standards set forth in paragraph 5.1.1 of this regulation (Tier III), than that replacement engine shall meet the standards set forth in paragraph 4 of this regulation (Tier II). Guidelines are to be developed by the Organization to set forth the criteria of when it is not possible for a replacement engine to meet the standards in paragraph 5.1.1 of this regulation.

2.3 A marine diesel engine referred to in paragraph 2.1.2 or 2.1.3 of this regulation shall meet the following standards:

2.3.1 for ships constructed prior to 1 January 2000, the standards set forth in paragraph 3 of this regulation shall apply; and

2.3.2 for ships constructed on or after 1 January 2000, the standards in force at the time the ship was constructed shall apply.

Tier I

3. Subject to regulation 3 of this Annex, the operation of a marine diesel engine that is installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emissions of NO_2) from the engine is within the following limits, where *n* = rated engine speed (crankshaft revolutions per minute):

3.1 17.0 g/kWh when *n* is less than 130 rpm;
3.2 $45 \cdot n^{(-0.2)}$ g/kWh when *n* is 130 or more but less than 2000 rpm;
3.3 9.8 g/kWh when *n* is 2000 rpm or more.

Tier II

4. Subject to regulation 3 of this Annex, the operation of a marine diesel engine that is installed on a ship constructed on or after 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emissions of NO_2) from the engine is within the following limits, where *n* = rated engine speed (crankshaft revolutions per minute):

4.1 14.4 g/kWh when *n* is less than 130 rpm;
4.2 $44 \cdot n^{(-0.23)}$ g/kWh when *n* is 130 or more but less than 2000 rpm;
4.3 7.7 g/kWh when *n* is 2000 rpm or more.

Tier III

5.1 Subject to regulation 3 of this Annex, the operation of a marine diesel engine that is installed on a ship constructed on or after 1 January 2016:

5.1.1 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emissions of NO_2) from the engine is within the following limits, where *n* = rated engine speed (crankshaft revolutions per minute):
5.1.1.1 3.4 g/kWh when *n* is less than 130 rpm;
5.1.1.2 $9 \cdot n^{(-0.2)}$ g/kWh when *n* is 130 or more but less than 2000 rpm;
5.1.1.3 2.0 g/kWh when *n* is 2000 rpm or more;
5.1.2 is subject to the standards set forth in paragraph 5.1.1 of this regulation when the ship is operating in an emission control area designated under paragraph 6 of this regulation; and
5.1.3 is subject to the standards set forth in paragraph 4 of this regulation when the ship is operating outside of an emission control area designated under paragraph 6 of this regulation.

5.2 Subject to the review set forth in paragraph 10 of this regulation, the standards set forth in paragraph 5.1.1 of this regulation shall not apply to:
5.2.1 a marine diesel engine installed on a ship with a length (*L*), as defined in regulation 1.19 of Annex I to the present Convention, less then 24 metres when it has been specifically designed, and is used solely, for recreational purposes; or
5.2.2 a marine diesel engine installed on a ship with a combined nameplate diesel engine propulsion power of less than 750 kW if it is demonstrated, to the satisfaction of the Administration, that the ship cannot comply with the standards set forth in paragraph 5.1.1 of this regulation because of design or construction limits of the ship.

Emission control area

6. For the purposes of this regulation, emission control areas shall be:

6.1 the North America area, which means the area described by the coordinates provided in appendix VII to this Annex; and
6.2 any other sea area, including any port area, designated by the Organization in accordance with the criteria and procedures set forth in appendix III to this Annex.

Marine diesel engines installed on a ship constructed prior to 1 January 2000 (partly)

7.1 Notwithstanding paragraph 1.1.1 of this regulation, a marine diesel engine with a power output of more than 5000 kW and a per cylinder displacement at or above 90 litres installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000 shall comply with the emission limits set forth is paragraph 7.4 of this regulation.

7.4 Subject to regulation 3 of this Annex, the operation of a marine diesel engine that is installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emissions of NO_2) from the engine is within the following limits, where *n* = rated engine speed (crankshaft revolutions per minute):

7.4.1 17.0 g/kWh when *n* is less than 130 rpm;
7.4.2 $45 \cdot n^{(-0.2)}$ g/kWh when *n* is 130 or more but less than 2000 rpm;
7.4.3 9.8 g/kWh when *n* is 2000 rpm or more.

Regulation 14; *Sulphur oxides (SO_X) and particulate matter*

General requirements

1. The sulphur content of any fuel oil used on board ships shall not exceed the following limits:

1.1 4.50% m/m prior to 1 January 2012
1.2 3.50% m/m on and after 1 January 2012
1.3 0.50% m/m on and after 1 January 2020

2. The worldwide average sulphur content of residual oil supplied for use on board ships shall be monitored taking into account guidelines developed by the Organization.

Requirements within emission control areas (partly)

3. For the purpose of this regulation, emission control areas shall include:

3.1 the Baltic Sea area as defined in regulation 1.11.2 of Annex I and the North Sea as defined in regulation 5.1(f) of Annex V;
3.2 the North American area as described by the coordinates provided in appendix VII to this Annex; and
3.3 any other sea area, including any port area, designated by the Organization in accordance with the criteria and procedures set forth in appendix III to this Annex.

4. While ships are operating within an emission control area, the sulphur content of fuel oil used on board ships shall not exceed the following limits:

4.1 1.50% m/m prior to 1 July 2010;
4.2 1.00% m/m on and after 1 July 2010; and
4.3 0.10% m/m on and after 1 January 2015

5. The sulphur content of fuel oil referred to in paragraph 1 and paragraph 4 of this regulation shall be documented by its supplier as required by regulation 18 of this Annex.

7. During first twelve months immediately following an amendment designating a specific emission control area under paragraph 3 of this regulation, ships operating in that emission control area are exempt from the requirements in paragraph 4 and 6 (not presented here) of this regulation and from requirements in paragraph 5 of this regulation insofar as they relate to paragraph 4 of this regulation.

Annex 5 Wind analysis

Table 10.1; measured NO_X concentration data by monitoring stations at Nordeney and Kollumerwaard. The background concentration is determined with this data. Measured data concerning SO_2 and PM showed limited variation and are therefore excluded in this analysis. This data is also used to determine the concentration trend for NO_X with time, wind direction, or wind speed. Wind direction is the largest determinant in NO_X concentration trend (R^2=0.23).

Date	Time	Wind direction		Speed (km hr^{-1})	Nordeney NO_X (µg m^{-3})	Kollumerwaard NO_X (µg m^{-3})
30-aug	0:00	233	SW	2,2	5	
30-aug	4:00	235	SW	3,9	2	
30-aug	8:00	224	SW	4,3	5	
30-aug	12:00	212	SSW	5,3	4	
30-aug	16:00	227	SW	4,2	2	
30-aug	20:00	288	WNW	1,4	5	
31-aug	0:00	336	NNW	0,3	6	
31-aug	4:00	356	N	3,9	3	
31-aug	8:00	37	NE	6,4	3	
31-aug	12:00	358	N	9,7	2	
31-aug	16:00	339	NNW	8,2	2	
31-aug	20:00	330	NW	6,8	2	
1-sep	0:00	325	NW	5,6	2	
1-sep	4:00	325	NW	4,7	2	
1-sep	8:00	311	NW	2,9	2	
1-sep	12:00	269	W	2,7	3	
1-sep	16:00	253	WSW	3,5	2	
1-sep	20:00	208	SSW	3,2	4	
2-sep	0:00	192	SSW	4,2	5	
2-sep	4:00	193	SSW	5,2	10	
2-sep	8:00	198	SSW	5,1	12	
2-sep	12:00	205	SSW	5,6	8	
2-sep	16:00	239	WSW	3,4	8	
2-sep	20:00	275	W	1,3	4	
3-sep	0:00	253	WSW	1,8	3	
3-sep	4:00	291	WNW	2	3	
3-sep	8:00	299	WNW	2,1	3	
3-sep	12:00	301	WNW	3,5	2	
3-sep	16:00	313	NW	3,4	2	
3-sep	20:00	244	WSW	1,2	3	
4-sep	0:00	234	SW	1,7	3	
4-sep	4:00	214	SW	3,2	9	
4-sep	8:00	198	SSW	4	9	
4-sep	12:00	223	SW	5,8	9	
4-sep	16:00	263	W	4,6	14	
4-sep	20:00	320	NW	4	4	
5-sep	0:00	307	NW	4	2	
5-sep	4:00	319	NW	4,3	2	

5-sep	8:00	310	NW	4,3	2	
5-sep	12:00	308	NW	3,7	2	2
5-sep	16:00	321	NW	6,3	2	2
5-sep	20:00	312	NW	5,4	2	1
6-sep	0:00	325	NW	5,9	2	1
6-sep	4:00	322	NW	4,2	5	6
6-sep	8:00	309	NW	3,1	2	2
6-sep	12:00	264	W	3,9	2	4
6-sep	16:00	250	WSW	4,8	2	2
6-sep	20:00	236	SW	5,3	2	5
7-sep	0:00	229	SW	7,7	4	6
7-sep	4:00	244	WSW	5,2	8	9
7-sep	8:00	263	W	3,9	5	8
7-sep	12:00	267	W	4,6	3	4
7-sep	16:00	275	W	4	2	1
7-sep	20:00	257	WSW	3,3	5	2
8-sep	0:00	270	W	3,4	4	3
8-sep	4:00	242	WSW	2,8	9	6
8-sep	8:00	265	W	3,2	7	12
8-sep	12:00	265	W	4,1	10	4
8-sep	16:00	271	W	3,1	7	2
8-sep	20:00	319	NW	1,2	2	3
9-sep	0:00	151	SSE	1,7	7	11
9-sep	4:00	137	SE	2,7	6	6
9-sep	8:00	125	SE	3,4	8	8
9-sep	12:00	145	SE	3,6	4	7
9-sep	16:00	152	SSE	3,8	4	6
9-sep	20:00	123	SE	2,1	7	6
10-sep	0:00	198	SSW	2,6	5	9
10-sep	4:00	190	S	4,8	10	8
10-sep	8:00	205	SSW		12	12
10-sep	12:00	217	SW		10	8
10-sep	16:00	219	SW		8	7
10-sep	20:00	214	SW		6	17
11-sep	0:00	179	S		11	7
11-sep	4:00	189	S		8	7
11-sep	8:00	206	SSW		10	15
11-sep	12:00					12
11-sep	16:00					3

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